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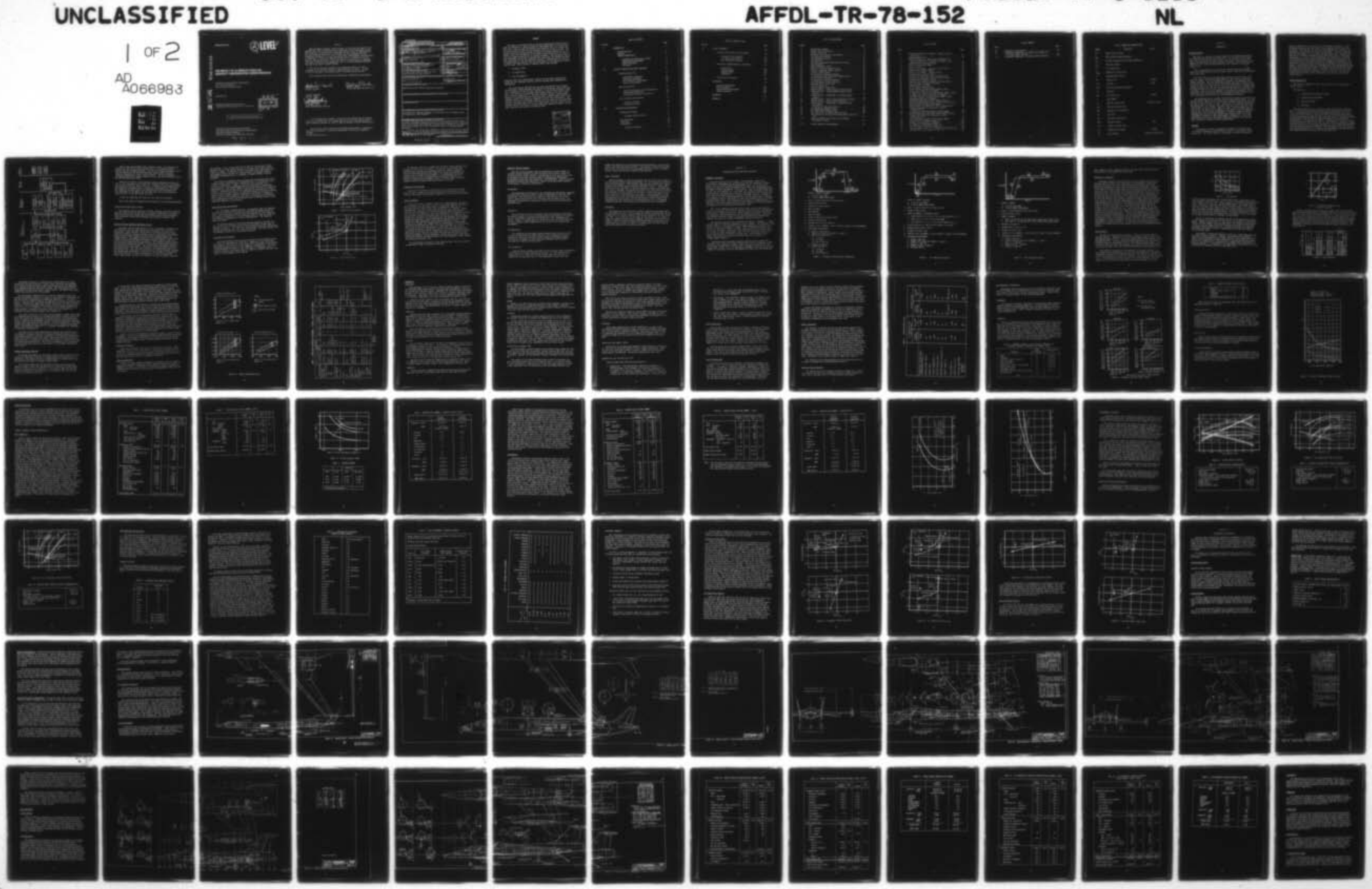

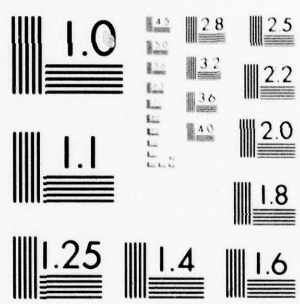


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# THE IMPACT OF ALTERNATE FUELS ON AIRCRAFT CONFIGURATION CHARACTERISTICS

*ROCKWELL INTERNATIONAL CORPORATION*
*LOS ANGELES DIVISION*
*LOS ANGELES, CALIFORNIA 90009*

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OCTOBER 1978



TECHNICAL REPORT AFFDL-TR-78-152
Final Report for Period December 1977 – October 1978

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AIR FORCE FLIGHT DYNAMICS LABORATORY
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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The study dealt with the effect of alternate fuel usage for three classifications of advanced technology vehicles for a post-2000 time period. Alternate fuel design vehicles were configured to optimum thrust loading and wing loading based on hydrocarbon (JP-4) fuel, and found to offer 35 to 45 percent weight reduction.

Life-cycle cost savings were estimated as a function of fuel cost and showed fuels 10 to 15 times the basepoint resulted in breakeven LCC with the more exotic fuels.

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SUMMARY

The Impact of Alternate Fuels on Aircraft Configuration Characteristics study was conducted to identify potential replacement fuels for hydrocarbon-fuel (JP-4), and to assess the effects resulting from the use of those fuels on current inventory vehicles and conceptual vehicles of the year 2000. The current inventory vehicles studied included the aircraft responsible for the highest total fuel consumption and the three latest additions to the inventory which might become one of the leading consumers. The conceptual vehicles were developed from current technology with projections for advanced technologies applicable to the time period in question. Conventional JP-4 was used to develop baseline vehicles from which assessment of the conceptual vehicles could be made. Three classes of vehicles under study included:

1. Strategic strike

2. Air superiority

3. Area interception

Alternate fuels were selected which resulted in the lowest takeoff gross weight for the conceptual vehicles, and two versions were configured for each mission.

The study results show that the two fuels selected for the strategic strike mission (liquid hydrogen and nuclear) had no payoff, being worse than the JP basepoint in terms of cost (nuclear) or cost and effectiveness (hydrogen). This result is in agreement with another study on very large (transport) aircraft (Reference 1). The small aircraft, however, showed weight benefits of 40 percent and over which resulted in effectiveness benefits and probable flyaway cost reductions compared to the JP fuel counterparts. Preliminary life-cycle cost figures indicate that fuel costs for the pentaborane and boron alternate fuels of 10 to 15 times current JP prices result in comparable life-cycle costs for a 10-year, peacetime operation scenario for both small vehicles, each using two alternate fuels.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| Symbol | Definition | Units |
| --- | --- | --- |
| AR | Aspect ratio of wing | - |
| $C_{D_f}$ | Skin friction drag coefficient | - |
| $C_{D_i}$ | Induced (drag-due-to-lift) drag coefficient | - |
| $C_{L_\alpha}$ | Lift curve slope | - |
| $C_L$ | Lift coefficient | - |
| $C_{L_{max}}$ | Maximum lift coefficient | - |
| e | Wing efficiency factor | - |
| FC | Flyaway cost | dollars |
| h, H | Altitude | feet |
| IOC | Initial operational capability | - |
| IR | Infrared | - |
| LCC | Life-cycle cost | dollars |
| M | Mach number | - |
| $P_s$ | Specific excess power | feet per second |
| psf | Pounds per square foot | - |
| SFC | Specific fuel consumption | - |
| SL | Sea level | - |
| SLS | Sea-level standard day | - |
| TOD | Takeoff distance | feet |
| T/W | Thrust to weight ratio | - |
| $W_o$ | Takeoff gross weight | pounds |
| W/S | Wing loading | pounds per square foot |

Section I

INTRODUCTION

PROGRAM OVERVIEW

The politics, economics, and world supply of petroleum-energy sources have been much discussed in the recent past. The very finite world supply would seem to indicate that these aspects can only become more critical as supplies become smaller and more difficult to extract. The difficulties and complexities of a solution have delayed even the statement of a national energy policy.

Such a large proportion of our nation's energy needs are now being supplied by petroleum that alternate sources must be identified and developed on an urgent basis.

The ideal fuel would have high-energy content, be low in cost, be in plentiful supply, have good storage properties, and be easily accessible, compact, portable, safe, environmentally acceptable, and compatible with aircraft materials. Because liquid hydrocarbons rank high in each of these categories, they have long been the choice for aircraft fuels. However, the energy problems of the last few years (diminishing supplies, increased costs) have made evident the fact that alternate fuel sources for aircraft must be considered. Fuels which have appeared to be undesirable because of cost or development time required must now be reevaluated and their effects on aircraft configuration characteristics and performance determined.

The configurations of aircraft, and military aircraft in particular, may be most heavily impacted by alternate types of nonpetroleum fuels. To study, develop, and put into service a new aircraft concept using an alternate fuel may require up to 10 years, or more. Therefore, as an initial step toward developing such a new concept, the impact that the type of fuel has on the total system in terms of cost, logistics, safety, and performance must be identified. The chief area of concern in this study is the contribution of the new fuel to the vehicle configuration. Potential changes to vehicle configurations due to new fuel concepts could require years of test and development to produce a viable and economic configuration. Thus, this study provides an initial step toward defining the impact that alternate fuels could have on future aircraft configurations.

APPROACH

The approach selected to accomplish the impact of alternate fuels on aircraft configuration characteristics study is a filtering or screening process. The initial inputs of requirements, mission, and payload

data were enhanced with a selected list of technology candidates. These technology candidates were the result of a technology identification and assessment effort dealing with the year 2000 technologies in the areas of aerodynamics, propulsion, structures, and materials. Advanced technologies offering improvements in cost, weight, and performance were identified and analyzed as to probable availability date and system impact. From these technologies, a list of selected technologies was prepared and integrated into the baseline aircraft concepts for each mission or system type. The configuration filtering process proceeded by accomplishing optimization and sensitivity analyses on these baseline vehicle concepts, and assessing the impact of the alternate fuels on the parametrically derived optimum vehicles. The fuels showing the most promise were selected, and configuration concepts were developed around these fuels. A technical analyses of the resulting configurations verified the parametric results. The final versions were assessed for performance, cost, reliability, survivability, and system safety effects.

## PROGRAM ORGANIZATION

The study was conducted in four tasks, as shown in the program flow diagram, Figure 1.

The tasks are:

I - Evaluation and selection of fuels

II - Configuration development

III - Impact assessment

IV - Reporting

The initial step of task I involves a search for potential alternate fuels. Considerable effort had previously been accomplished in this field and, to avoid duplication of effort, advantage of this effort was taken. A critical link in the task I activities was to develop evaluation criteria by which representative alternate fuels and their necessary propulsion systems characteristics were selected for impact assessment on typical vehicle configurations in preparation for task II. Simultaneously, baseline vehicles were synthesized for each of the three aircraft roles (air superiority fighter, strategic strike vehicle, and area interceptor), using conventional petroleum fuel to establish a point of reference. The end items of this task include the selected alternate fuels to proceed into configuration development and the petroluem-fueled baseline vehicle for each mission role.

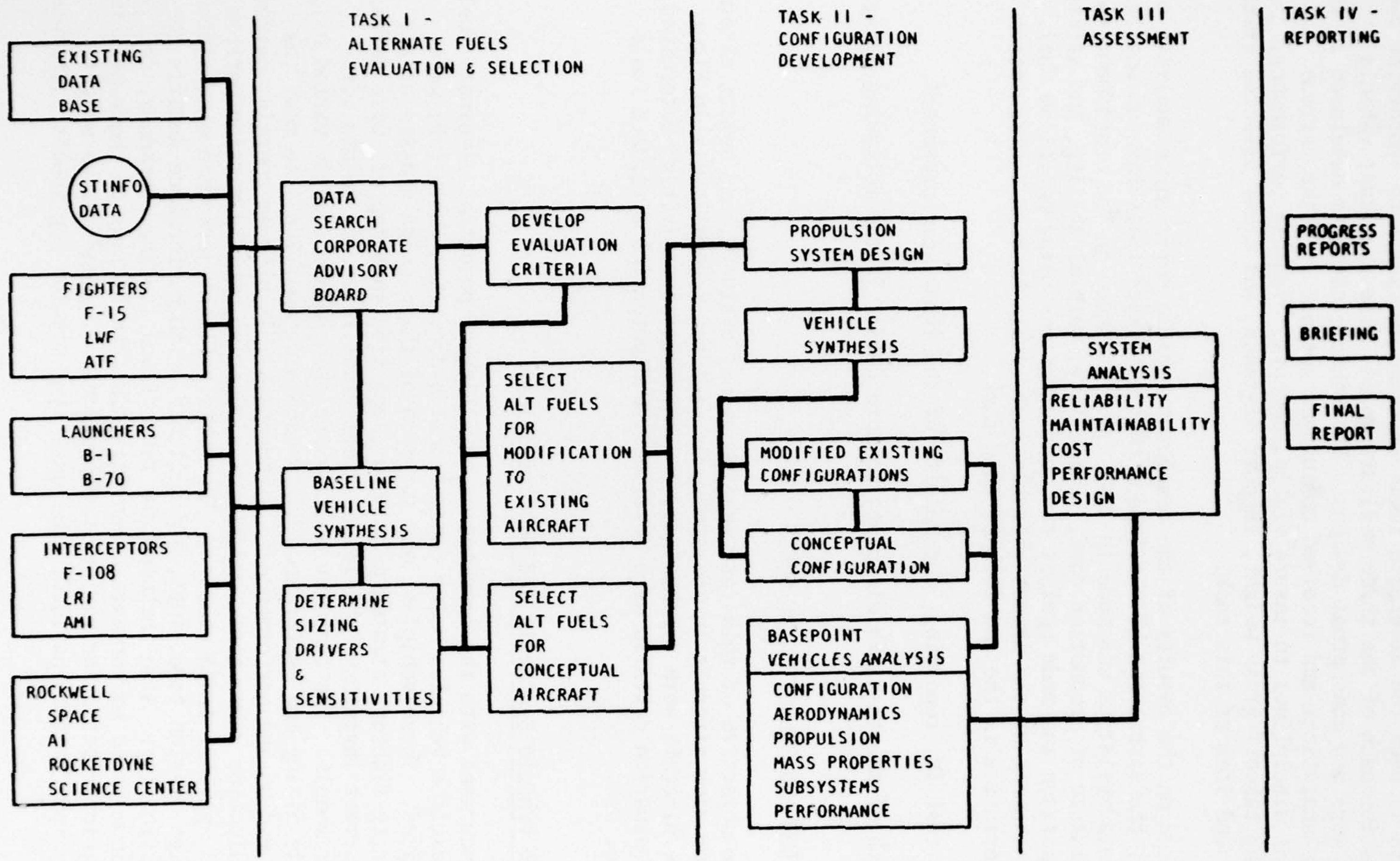



Figure 1. Program flow diagram.



An advanced transonic (or supercritical) wing design has also been selected for the strike vehicle. Figure 9 shows the total drag breakdown for a variable sweep wing vehicle and a fixed wing vehicle for comparison.

Task II uses the alternate fuels selected in task I to synthesize two vehicles for each of the three military roles. The resultant vehicle designs were new conceptual designs. The vehicle concepts developed in this task are analytical and received consultant support from the various technical disciplines to insure viable concepts. Vehicle performance, including takeoff gross weight, takeoff distance, and other selected criteria was the end item of this task.

Based on the results of the basepoint vehicle performance analysis of task II, the assessment of the impact that alternate fuels have on configuration characteristics was made in task III. Included in the assessment were the influence of production cost, reliability, maintainability, and safety. The comparison was made against the configurations using petroleum fuel. This assessment of the impact that alternate fuels have on configuration characteristics is the end item of this task.

In task IV, reporting, the results of the study were presented.

Each of the tasks is discussed in more detail in the following paragraphs.

## EVALUATION AND SELECTION OF FUELS

The objective of this task was to define, evaluate, and select alternate fuels for each aircraft in the study, as depicted schematically in Figure 1. Baseline aircraft were synthesized, and aircraft sensitivities determined. Fuels evaluation criteria were developed, and potential alternate fuels selected.

### Baseline Vehicle Synthesis and Sensitivities

Concurrent with the compilation of a list of potential alternate fuels, three baseline vehicles using conventional hydrocarbon fuels (JP) were synthesized. These vehicles, one for each of the mission classes of air superiority fighter, strategic launcher, and area interceptor, were defined using current inventory vehicles as statistical reference points for computer models. The computer models were then parametrically varied using a Vehicle Sizing and Performance Estimation program (VSPEP) to meet the mission radius and performance requirements. This program contains performance evaluation subroutines capable of simulating vehicle mission performance and optional trade studies. The vehicle flight performance consists of the design mission time, fuel, and distance, with performance details for each mission leg. Also included are takeoff and landing distances, ceilings, and maximum speed performance. Sensitivities can be made on these performance characteristics for various combinations of takeoff gross weight (TOGW), empty weight, payload, fuel quantity, mission leg speeds, altitudes,

and distances. Also, sizing trades can be made for various major design variables such as wing loading, engine size, design gross weight, payload weight, or volume. In addition to these performance and trade capabilities, the program contains routines for scaling weights, aerodynamic geometry, and propulsion characteristics in response to command changes to design variables.

The results of parametric thrust-loading and wing-loading trades allow a figure of merit (such as TOGW or production cost) to be minimized within a series of constraints. Figure 2 illustrates this procedure for a typical vehicle. The minimum-weight vehicles which met or exceeded the requirements for each mission served as the baseline vehicles for comparison purposes. Because these vehicles are computerized reference points indicative of current state-of-the-art, no detailed drawings of them were produced. Sensitivities of weight, maneuver performance, and radius to changes in thrust, specific fuel consumption, and zero lift-drag were also parametrically generated and used as an evaluation filter to determine the alternate fuels most adaptable to each mission.

### Fuels Evaluation and Selection

In a preliminary screening process, the candidate fuels for inventory aircraft were assessed for the ability to perform the design mission of each. Those fuels which contained sufficient energy were then evaluated with regard to compatibility with existing systems in terms of safety and consideration of adaptation to vehicle configurations. The remaining fuels were noted.

The aircraft sensitivities derived from the basepoint aircraft were used to select two alternate fuels for each conceptual aircraft type, as depicted in Figure 3. The reference line represents equivalent performance, trading fuel heating value (SFC) with vehicle drag. The fuels furthest from the reference line provide the greatest potential.

## CONFIGURATION DEVELOPMENT

Using the potential alternate fuels selected in the screening process of task I, the configurations required or suggested by these fuels were investigated. The objective of the study is to investigate the performance and design characteristics of these suggested configurations. To provide a broad spectrum of vehicles in the investigation, different classes of military aircraft were covered, from air superiority fighter and area interceptor, to the strategic strike vehicle.

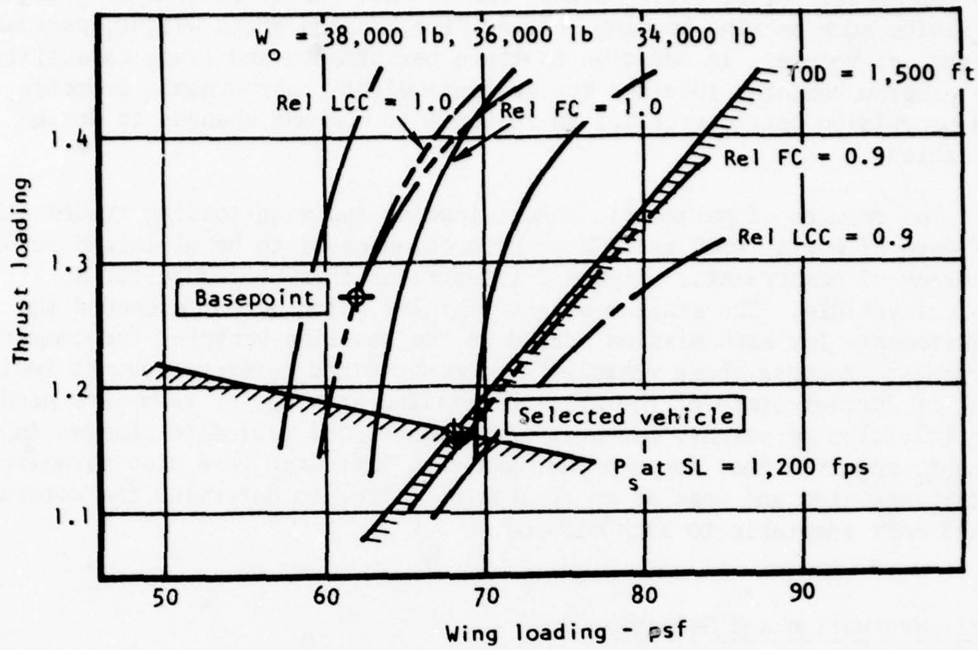



Figure 2. Typical vehicle selection.

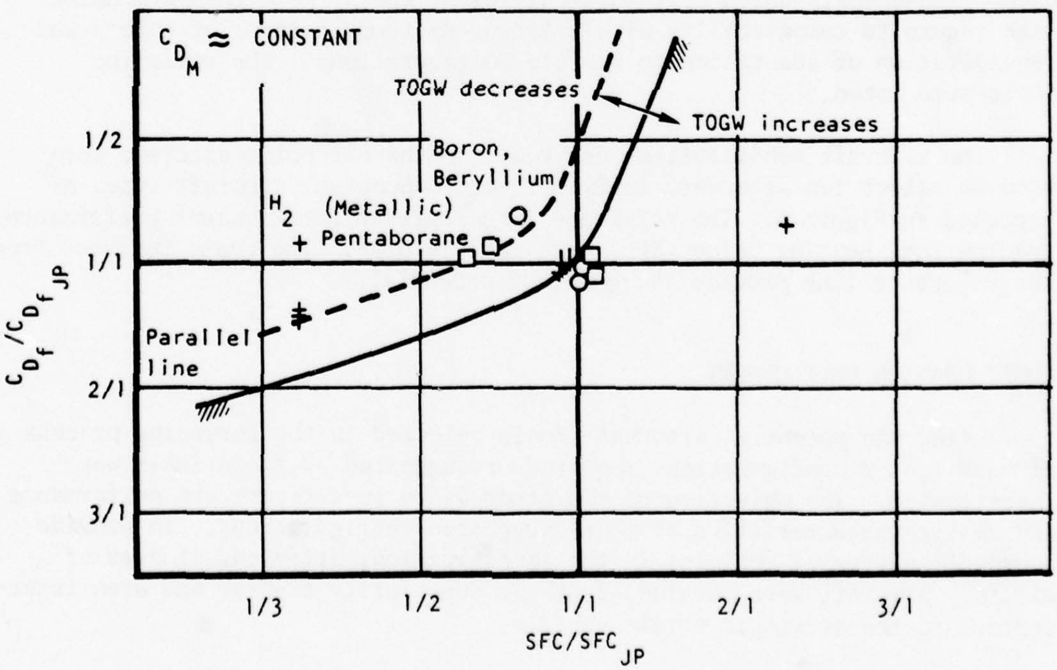



Figure 3. Typical trade lines.

The approach used was to evaluate the influence of two alternate fuel concepts for each class of aircraft. The plan was to incorporate the alternate fuel concepts into conceptual aircraft, identify configuration and subsystems modifications required to accept the alternate fuel concept, and to evaluate the performance. The performance and design characteristics of these configurations were evaluated against the baseline configurations performance frame of reference which was established in task I for each of the three classes of aircraft.

Propulsion System Design

Based on the information available from the selection of alternate fuels in task I, propulsion system characteristcs were defined for each aircraft, and propulsion performance adequate for aircraft sizing estimated.

Vehicle Synthesis

The task II vehicle synthesis consists of integrating the alternate fuels selected as an end item in task I as potential, feasible solutions to the study objective into viable vehicles showing the impact on the configuration. For each mission class of vehicle (i.e., fighter, strike vehicle, and interceptor), two of the alternative fuels were selected for a total of six vehicles. To use the alternative fuel concepts, existing aircraft were surveyed to determine their feasibility as candidates for modification to perform the desired missions, and alternate fuel conceptual designs were generated. These preliminary design vehicles were evaluated against the same requirements as the baseline vehicles of task I. The sizing of all designs was accomplished by a combination of rapid manual statistical methodology and VSPEP. The manual procedure (1) relies on the identification of key design parameters associated with that concept, (2) assumes aerodynamic, propulsion, and mass properties characteristics reflecting the state-of-the-art technologies, and (3) determines the vehicle TOGW based on fuel required to perform the design mission and meet other design requirements. Design experience, related study results, and interdiscipline interface are used to define the vehicle geometry, thrust loading, wing-loading, and engine cycle.

The performance evaluation of these vehicles and/or initial sizing was accomplished by VSPEP as previously described.



Components

Compressors

## Basepoint Vehicle Analysis

Once the sizing parameters had been determined for each concept, an iterative analysis process was used to allow the total vehicle system to crystallize into a viable concept. Contributing to this task at this level of the design cycle were the disciplines of configuration development, aerodynamics, propulsion, mass properties, and subsystems. These disciplines provided consultant-type expertise to resolve the design problem involved in developing a conceptual configuration.

### Aerodynamics

The aerodynamics contribution to the configuration development conceptual configurations consisted of state-of-the-art technology for the year 2000 time period. The contributions to vehicle sizing include lift-to-drag ratios, induced-drag factors, zero lift-drag, and wave-drag levels. The aerodynamic characteristics defined for each of the aircraft evaluated are presented later.

### Propulsion

The propulsion analysis of basepoint vehicles consisted of monitoring the vehicle concepts to validate the propulsion system influence in terms of airflow requirements compatible with the specific fuel consumption and thrust. Geometric considerations of inlets and nozzles were also monitored to insure engine/airframe compatibility and to aid in the configuration development.

### Configurations

The configuration development group prepared design concepts to meet mission and fuel/propulsion specifications. The preparation of design concepts for analysis, including external geometry-aerodynamic shaping and internal arrangement of major subsystem components and structure, initiates the iterative design process.

### Mass Properties

Baseline weight estimates were made for each aircraft under consideration using statistical weight-estimating procedures. For the configurations using unique and or innovative design concepts where the statistical methods are not applicable due to a non-representative data base, the



Current augmenters tend to be nearly 4 feet long to achieve these efficiency

weights were modified as required based on design experience, related study results, and interdiscipline interface. The baseline configuration weights were scaled within the vehicle sizing program during the vehicle synthesis process, using classical-type weight scaling equations.

## IMPACT ASSESSMENT

Having developed at least two configurations for each of the classes of aircraft using alternate nonpetroleum fuels, this task assessed the merits of these vehicle concepts. The assessment technique was to establish a figure of merit based on the baseline aircraft generated in task I. These task I aircraft are year 2000 state-of-the-art technology vehicles using petroleum fuel sized to represent the minimum TOGW vehicle for each respective mission. The assessment criteria includes the influence of production and life-cycle cost, reliability, maintainability, and safety. Since advancement in the state-of-the-art in the technology disciplines for aerodynamics, materials, and propulsion did not enter into the evaluation of these alternate fuel configurations, the influence of the replacement fuel and its subsequent systems provided the sole influence to be evaluated in this assessment.

## CONCLUSION

The purpose of this study was to identify potential replacement fuels for hydrocarbon fuel (JP-4) and to assess the effects resulting from the use of those fuels on current inventory vehicles and conceptual vehicles of the year 2000. As is necessary for any study of this nature, it is limited in scope, and numerous fuel mixtures, compounds, and derivatives were not considered. Areas of potential benefit were identified and guidelines established which can be used to provide a filtering screen for other fuels in which the reader may have a particular interest.

## Section II

## BASELINE SELECTION AND FUELS SELECTION

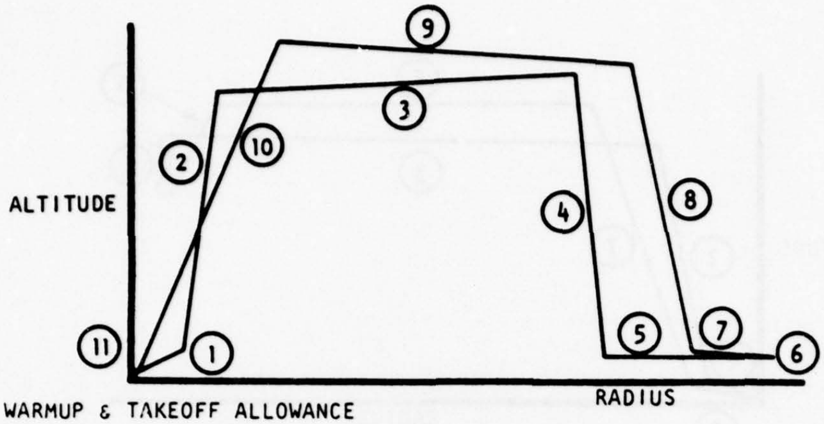
### TECHNOLOGY SELECTION

Since the earliest days of flight, an evolutionary, rather than revolutionary, development has continued such that most features of todays vehicles may be traced through the development cycle. Use of this fact allows an estimate of future developments to be made and a determination of the impact of those developments to be assessed. This is the philosophy used in task I of this program; i.e., to estimate the technical growth in the areas of aerodynamics, materials/mass properties, and propulsion and determine what effect that growth would have on a current technology vehicle. A change in fuel, however, to one of nonhydrocarbon base is more revolutionary in nature, as the substance but not the quality of fuels has remained virtually constant from the earliest days. The assessment of the impact of changing fuels is, therefore, a less well-defined task, but one of necessity in view of diminishing supplies of the "conventional hydrocarbon" fuels.

The current technology baseline vehicles used in this study were the B-52H for a strategic strike mission and the F-15A for both an air superiority mission and an interceptor mission. These vehicles were used as data bases for parametric vehicle optimization for the respective missions. The use of these vehicles presents a known starting point from which to proceed and evaluate the effects of mission, technology, and fuels selection.

The aforementioned missions are defined in Figures 4 through 6. These profiles show the missions as modified in task I studies. The strategic strike mission (Figure 4) was modified to have longer penetration and egress distances at a fixed Mach number, as shown. The air superiority mission (Figure 5) was modified by reduction of the warmup and takeoff allowance and by an increase in combat requirements, while the area interceptor mission was given reduced warmup and takeoff allowance only. These changes reflect modern requirements for high-thrust-loading vehicles and desires for "longer-legged" fighters.

Technology trend development has been conducted on many nonrelated programs in the recent past (Highly Maneuverable Aircraft Technology (HiMAT), Ait-to-Surface Technology Evaluation (ATS), Innovative Strategic Aircraft Design Study (ISADS), etc), and the general agreement of the results of these studies is suprising in view of the disparity of objectives and assumptions




1. WARMUP & TAKEOFF ALLOWANCE

   A. 5 MIN AT IDLE POWER
   B. 1 MIN AT NORMAL RATED POWER

2. ACCEL & CLIMB TO CRUISE ALT AT MAX N MI/LB.

3. CRUISE AT MAX N MI/LB

4. DESCEND TO SL MAX N MI/LB.

5. DASH TO TARGET

6. DROP WEAPONS.

7. DASH OUT TARGET

8. CLIMB TO CRUISE ALT AT MAX N MI/LB.

9. CRUISE AT MAX N MI/LB.

10. DESCEND MAX N MI/LB TO 2,000 FT.

11. LANDING & TAXI ALLOWANCE - 20 MIN LOITER AT 2,000 FT AT MAX ENDURANCE

12. PERFORMANCE REQUIREMENTS

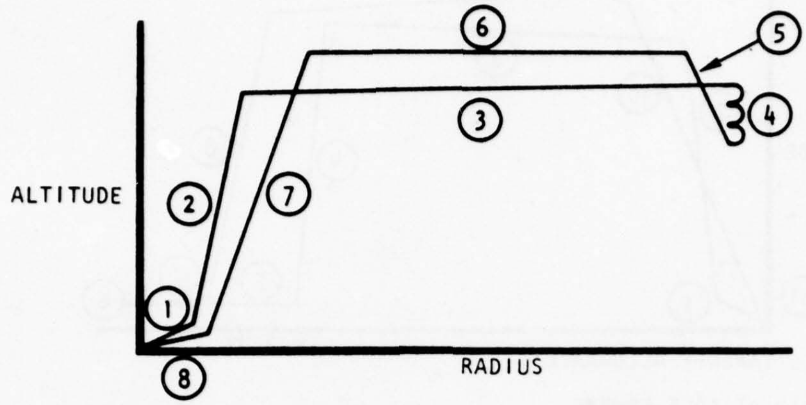
    A. RADIUS = 3,000 N MI FT
    B. TAKEOFF DIST (OVER 50 FT OBST) = 7,000 FT
    C. DASH INTO TARGET (LEG 5)

       (1) H = 50 FT
       (2) M = 0.85
       (3) DIST = 750 N MI

    D. PAYLOAD = 50,000 LB
    E. EGRESS DASH (LEG 7)

       (1) H = 50 FT
       (2) M = 0.85
       (3) DIST = 300 N MI

Figure 4. Strategic strike mission (unrefueled).




1. WARMUP & TAKEOFF ALLOWANCE

   A. 5 MIN AT IDLE POWER
   B. 2 MIN AT NORMAL RATED POWER

2. ACCEL & CLIMB TO CRUISE ALT AT MAX N MI/LB

3. CRUISE AT MAX N MI/LB

4. COMBAT ALLOWANCE AT MIDCOMBAT WEIGHT

   A. 2,880° TURN AT M = 0.9 & H = 30 K FT MAX POWER AT $P_S = 0$

   B. ACCEL TO M = 1.8 & H = 45K FT MAX POWER

   C. 720° TURN AT M = 1.6 & H = 45K FT MAX POWER AT $P_S = 0$

5. CLIMB TO CRUISE ALT = MAX N MI/LB (FROM 0.7 M AT 20K)

6. RETURN CRUISE AT MAX N MI/LB.

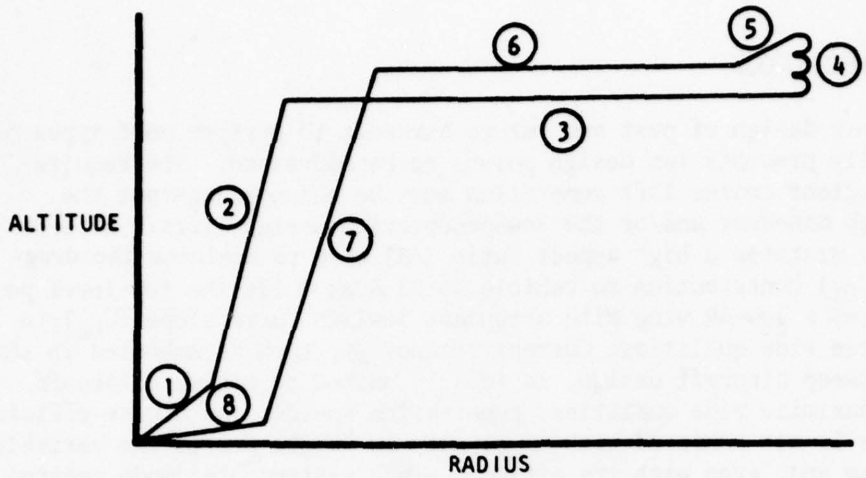
7. DESCEND TO 2,000 FT MSL.

8. LANDING & TAXI ALLOWANCE - 20 MIN LOITER AT 2,000 FT AT MAX ENDURANCE.

9. PERFORMANCE REQUIREMENTS

   A. RADIUS = 500 N MI
   B. TAKEOFF DIST (OVER 50 FT OBST) = 1,500 FT
   C. MAX $P_S$ = 1,200 FPS
   D. COMBAT CEILING = 60,000 FT
   E. PAYLOAD = 800 LB

Figure 5. Air superiority mission.




1. WARMUP & TAKEOFF
   - A. 5 MIN AT IDLE POWER
   - B. 1 MIN AT NORMAL RATED POWER
2. ACCEL & CLIMB TO CRUISE ALT AT MAX N MI/LB.
3. CRUISE AT MAX N MI/LB.
4. COMBAT ALLOWANCE
   - A. ACCEL & CLIMB FROM CRUISE CONDITIONS TO MAX MACH AT 60K FT PLUS
   - B. 360° TURN M = 2.0 AND 60K FEET AT MAX STEADY-STATE LOAD FACTOR
5. DESCEND TO CRUISE ALT.
6. RETURN CRUISE AT MAX N MI/LB.
7. DESCEND TO 2,000 FT MSL.
8. LANDING & TAXI ALLOWANCE - 20 MIN LOITER AT 2,000 FT AT MAX ENDURANCE.
9. PERFORMANCE REQUIREMENTS
   - A. RADIUS = 500 N MI
   - B. TAKEOFF DISTANCE OVER 50 FT OBSTACLE = 1,500 FT
   - C. MAX $P_S$ = 1,200 FPS
   - D. COMBAT CEILING 60,000 FT
   - E. PAYLOAD = 2,000 LB

Figure 6. Area intercept mission.

used. Because of this, wherever possible, previous study results were used to develop the trends expected for this study.

## AERODYNAMICS TECHNOLOGY

Aerodynamic design of past and future aircraft to perform most types of missions usually presents two design points to be addressed. The requirements for efficient cruise lift generation must be balanced against the relatively high maneuver and/or the low-penetration design lifts. Efficient cruise usually dictates a high aspect ratio (AR) wing to minimize the drag-due-to-lift ($C_{D_i}$) contribution to vehicle total drag while the low-level penetration dictates a low-AR wing with attendant lowlift curve slope ($C_{L_\alpha}$) to maximize vehicle ride qualities. Current technology, such as embodied in the B-1 variable sweep aircraft design, is ideally suited to minimize takeoff distance and maximize ride qualities, penetration speeds, and cruise efficiencies, but this is not achieved without penalty in weight due to the variable sweep mechanism and, even with its aftswept wing, a structural mode control system to enhance ride qualities. The variable sweep feature of the B-1 allows a low wing sweep angle to be used during cruise which, due to the resultant high AR, minimizes the $C_{D_i}$. Increasing the reduced $C_{L_\alpha}$ desirable at some cost in drag-due-to-lift. However, in the 1970-80 time frame, this manned aircraft system represents a most efficient approach to satisfying the high-low aerodynamic design points. Current technology fighters such as the F-15A and F-16A use low-to-moderate wing loadings and maneuvering flaps and leading edge devices to accomplish the match between cruise and maneuver requirements. Further developments in these and other areas will provide improvements for future vehicles. The selection of the most promising technologies will depend on the mission ground rules and the off-design performance desired.

### Strike Vehicle

The high-low mission profile presents a classic case of the mismatch mentioned earlier. Inspection of the lift requirements (Figure 7) for a low- and high-altitude cruise at a fixed wing loading reflects the mismatch of the wing design points. Clearly, the low-altitude penetration will optimize at a different wing size and geometry than will the higher altitude cruises. One solution to this problem is the nonplanar wing, which provides a dual effect on the vehicle drag. The first of the areas affected is the drag-due-to-lift.

The addition of winglets has the potential to increase airplane lift curve slope, reduce induced drag, provide directional stability, and increase aerodynamic efficiency at the design condition. The addition of winglets to a low-AR wing therefore can result in a wing which has the $C_{L_\alpha}$ and $C_{D_i}$ characteristics of a high-AR wing with the weight of the low-AR planform. The aerodynamics of this effect are associated with the span loading of the wing.

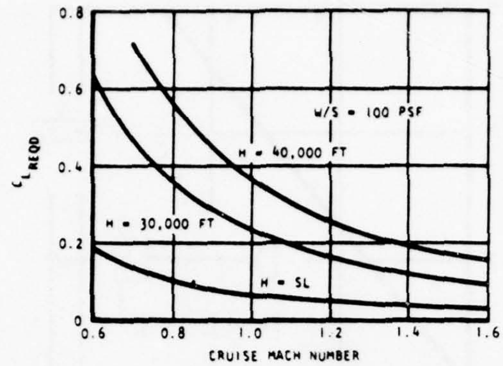



Figure 7. Lift required.

For the classical monoplane, the minimum induced drag is provided by a constant downwash across the span; this is given by an elliptical distribution of load. However, for nonplanar lifting configurations, the minimum induced drag is found to be associated with the vortex wake in the Trefftz plane on the wing. In these cases, where a winglet, vortex diffuser, or end plate compose a nonplanar lifting configuration, the wing efficiencies are increased above the classical span loading solution. To achieve the potential in efficiency, the aircraft wing and winglet must be designed to carry the loading for minimum induced drag of a nonplanar lifting surface.

The use of end plates as nonplanar devices on the wing produces similar overall effects on the vehicle, but the results are achieved in a different manner. Whereas winglets result in additional lift through the maximization of the tip vortex energy, the end plates reduce the normal tip losses thus creating a more two-dimensional flow. Because the end effect of improved aerodynamic efficiency in cruise is approximately the same, both devices were considered equal.

Improvement in theoretical drag-due-to-lift for a simple nonplanar wing end plate is shown in Figure 8. However, even though this technology is known, the full potential has never been achieved. Future applications will increase the effectiveness of such surfaces by allowing optimization techniques not yet available to be developed due to computational improvements of advanced computers. In this manner, the improvements in drag-due-to-lift will be reflected by increased effective wing aspect ratio.



TABLE 4. COMPOSITE MATERIAL WEIGHT SAVINGS

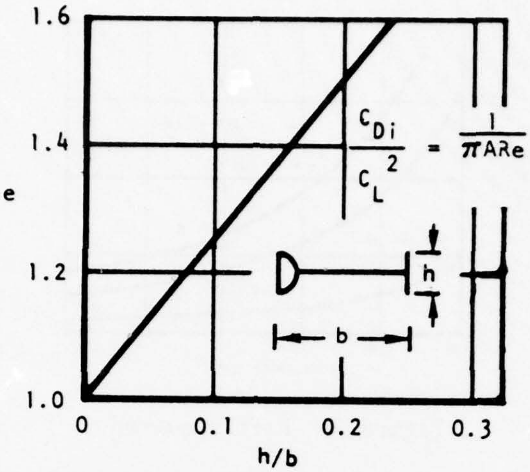



Figure 8. Theoretical nonplanar wing efficiency factors.

Current technology indicates that the largest share of the airplane resistance during penetration, and therefore the most fertile area for improvement, is in the viscous drag portion (Figure 9). Since skin friction represents as much as 60 percent of the vehicle resistance in penetration, the second effect of reducing wetted area through allowing higher wing loadings without changing drag-due-to-lift, as well as combining functions through directional stability, increases while improving lift efficiencies. This combination of features led to the selection of winglet surfaces for the strike vehicle.

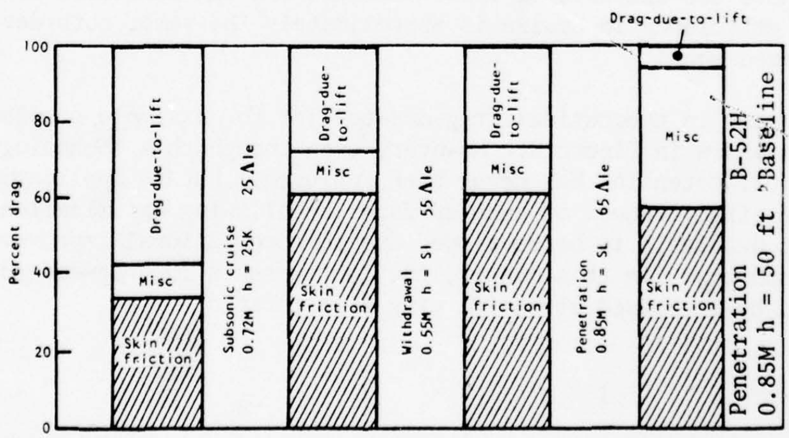



Figure 9. Drag breakdown.

An advanced transonic (or supercritical) wing design has also been selected for the strike vehicle. Figure 9 shows the total drag breakdown for a variable sweep wing vehicle and a fixed wing vehicle for comparison. For a fixed-wing vehicle (the B-52H is shown), the miscellaneous portion (compressible or wave drag) shows a large increase. The supercritical wing reduces this problem as will be discussed.

The experimental demonstration of a very low compressible drag rise through low supersonic speeds for a swept lifting wing-body configuration has been successfully accomplished by Bridgewater (Reference 2). The aspect-ratio 3.5 wing was swept 55 degrees and employed a 6-percent streamwise airfoil section. The twist and camber were defined to provide a "flattop" controlled subcritical flow with moderate upper surface adverse pressure gradients for a Mach 1.2, $C_L$ = 0.15 condition. The success of this design approach indicates avoidance of compressible pressure drag due to the formation of shockwaves and shock-induced boundary layer separation.

The logical extension of this wing flow philosophy to higher free-stream Mach numbers without recourse to increased wing sweep or thinner airfoil sections (or holding free-stream Mach for thicker sections of decreased wing sweep) is based on the development and exploitation of controlled (shockless or weak shock) supercritical flow airfoils. The three-dimensional (3-D) upper-surface wing target pressure distributions are still flattop but now would admit a local peak Mach number of 1.2, or greater, followed by an isentropic or weak-shock recompression.

The supercritical design implementation requires the iterative use of a 3-D transonic relaxation solution to the small-disturbance theory or the full-potential equation of motion, as opposed to the linearized design philosophy widely used for subcritical flows. Close attention must be given to viscous effects if required for the mixed-flow design as a result of the use of stronger pressure gradients. This can be accounted for by correcting the inviscid design wing contours for the effects of displacement thickness by undercutting.

## Fighter/Interceptor Vehicles

The design requirements for the fighter vehicles differ from the strike vehicles by requiring an increase in maximum usable lift coefficient for maneuvering. The primary means for accomplishing this increase with a minimum effect during cruise is through variable camber.

The variable camber wing concept employs leading and trailing edge geometry changes so that the wing camber can be varied for efficient operation over a wide variety of operations. The variable camber wing not only enables achievement of varying design lift coefficient, but also varying stability by planform extensions.

At the present time, there are basically two types of variable camber wings. In one type, leading and trailing edges simply deflect; in the other type, leading and trailing edges extend and deflect, thus providing an increase in wing area concurrently with variable camber. The result for both concepts is a higher usable $C_{L_{max}}$ over a broad Mach number range by preventing shocks and flow separation on the wing. Application of these devices can greatly improve loiter capability by reducing or eliminating flow low-speed manuever separation at high angles of attack, thereby improving lift/drag and thrust/drag available to maintain minimum level flight speeds.

To develop high-lift coefficients at altitude and speeds where compressible effects are significant, the airfoil section will be designed to maintain supercritical flow on the upper surface without producing shock-induced separation. The wing must be designed to produce high-lift coefficients and buffet boundaries while maintaining low viscous and potential pressure drag.

At the present time, on a conventional wing, the variable camber is achieved by a mechanical system, and the wing twist is achieved by a combination of mechanical and aeroelastic tailoring techniques. In the future, if a wing can be made of composite material, thereby eliminating the conventional wing box, both the wing twist and camber can be controlled by the aeroelastic tailoring technique or by an internal actuation system that forces the structure to deform to the desired shape without hinge line discontinuities. Systems of this type will permit maximum use of variable camber and also provide an alternative to variable sweep.

Overall zero-lift drag reduction at supersonic speeds is also of benefit to maneuver. This may be accomplished through wing-body blending and through the reduction of forebody buildup rate due to the influence of the canopy. A high-acceleration cockpit allows a reduced forebody and thereby reduces vehicle wave drag.

## PROPULSION TECHNOLOGY

Propulsion technology trends have been studied in four areas: engine technology, inlets, nozzles, and controls. The trends developed for these areas will be applied to the baseline vehicle propulsion characteristics to arrive at the modified baseline characteristics to be used for the study. Data for some of these values is presented in Figure 10.

### Engine Technologies

Advance in engine component technology and engine cycles will improve propulsion system performance and weight. Engine technology assessment is summarized in Table 1. Following is a discussion of engine component performance levels and engine cycles which may be considered for the year 2000 time period.

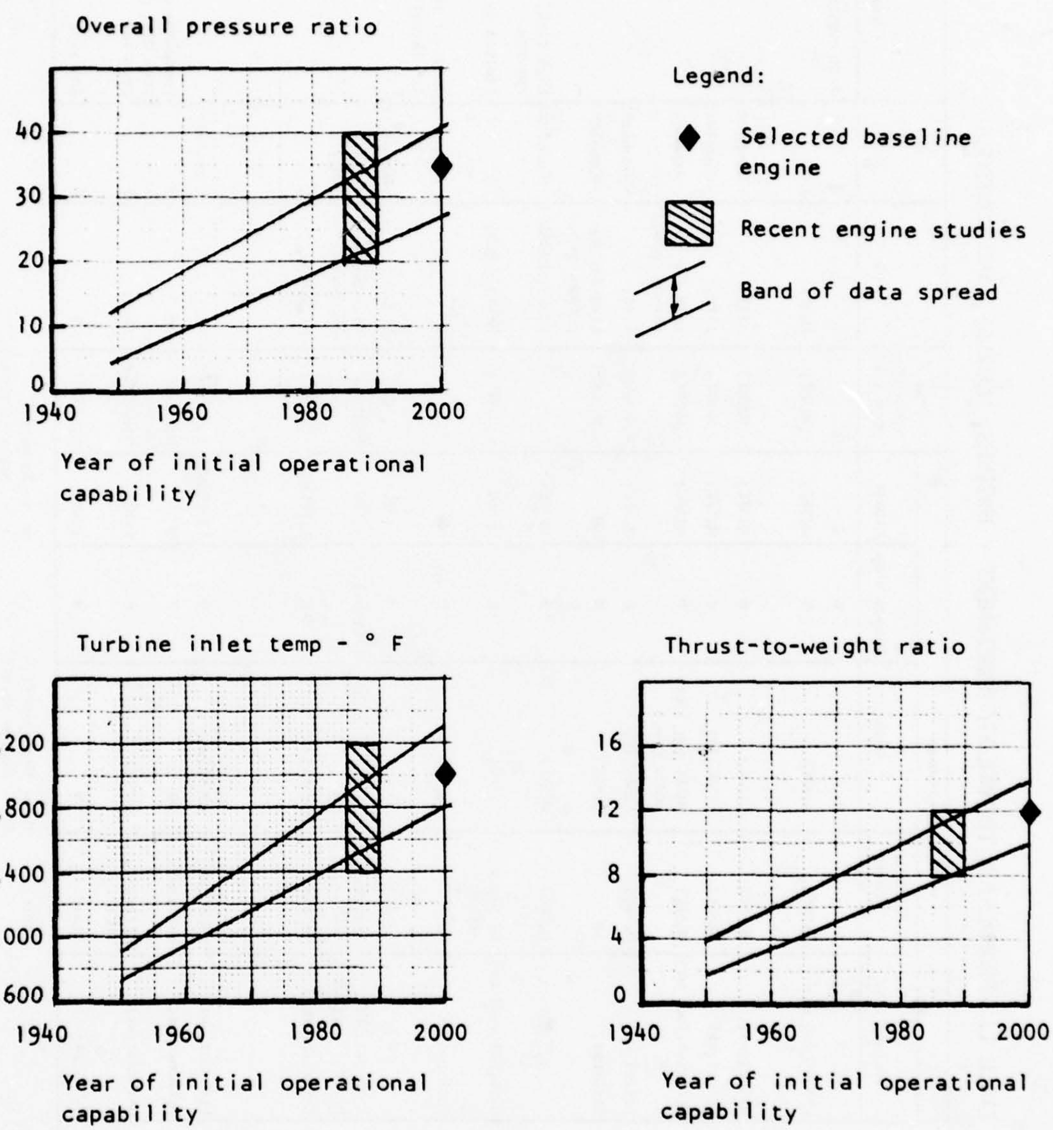



Figure 10. Engine technology trends.

TABLE 1. PROPULSION TECHNOLOGY ASSESSMENT - ENGINES, NOZZLES, AND CONTROLS

| Potential Technology | Mission segment: T.O. and Land | Climb and Cruise | Dash | Weapon Drop | Loiter | Cost (procurement, LCC) | S/V | Maint | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Current engine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Base engine |
| Advanced turbofan | L(fuel,eng wt) | M(SFC) | L(SFC) | 0 | M(SFC) | -,M(SFC) | M(IR) | L | |
| Variable-cycle engines | | | | | | | | | |
| VSCE | L(fuel,wt) | M(SFC) | L(SFC) | 0 | M(SFC) | -,M(SFC) | -(IR) | -(Complex) | |
| VABI | L(fuel,wt) | M(SFC) | L(SFC,IR) | 0 | M(SFC) | -,M(SFC) | L(IR) | -(Complex) | |
| MMIPS | M(thrust,fuel wt) | M(SFC) | M(SFC for supersonic pen.) | 0 | M(SFC) | -,M(SFC) | L(IR for superson. pen.) | -(Complex) | |
| Vari-flow rad comp | L(fuel wt) | M(SFC) | L(SFC,IR) | 0 | M(SFC) | -,M(SFC) | L(IR) | -(Complex) | |
| VGT Turbojet | L(thrust) | ~0 | L(SFC) | 0 | ~0 | -,M(SFC) | L(IR for superson. pen.) | -(Complex) | |
| Nuclear engine | ? | H(SFC) | H(SFC) | 0 | H(SFC) | ? | L(IR),-(DAMAGE) | -(Complex) | High risk, political, environ |
| Turboprop | M(thrust,fuel wt) | H(thrust, SFC) | L(SFC) | 0 | H(SFC) | L,H(SFC) | H(IR),-(RCS) | ~0 | Limited to mach 0.8 |
| RATO | H(thrust) | ~0 | ~0 | 0 | ~0 | - , - | 0 | -(Complex) | Indirect savings if T.O thrust sizing |
| Regen/Intercooled | ~0 | L(SFC) | ~0 | 0 | L(SFC) | - , 0 | L(IR) | -(Complex) | |
| Integrated controls - FFPC | L(Thrust,SFC, control surfaces) | L(thrust, SFC) | L(SFC) | L(stability) | L(SFC) | 0, M(SFC) | M(alternative opr modes) | M(self-diag) | |
| Nonaxisymmetric nozzles | L(thrust vect) | L(SFC) | L(SFC) | ~0 | L(SFC) | -,L(SFC) | M(IR,RCS) | L | |
| Engine component improvement | | | | | | | | | |
| Compressor | L(thrust, wt) | L(SFC,wt) | L(SFC,wt) | 0 | L(SFC,wt) | L, L(SFC) | ~0 | L(radial) | |
| Combustor | H(thrust,wt) | L(thrust) | ~0 | 0 | 0 | M(engine size) | ~0 | 0 | Combustor and turbine tech dvmt must coincide |
| Turbine (temp and cooling) | M(thrust,wt) | M(thrust, SFC) | L(SFC) | 0 | L(SFC) | M(engine | ~0 | 0 | |
| Augmenter | L(SFC,wt) | L(wt) | ~0 | 0 | L(wt) | L,L(SFC) | ~0 | 0 | Low risk |

Note: H - High payoff; M - Medium payoff; L - Low payoff; 0 - No payoff; - - Negative payoff; ? - Unknown until further study

## Components

### Compressors

Newly emerging 3-D flow analysis computer programs capable of analyzing and designing blade shapes should allow significant improvement in efficiencies in the year 2000 time period. Compressor and fan efficiency improvements of about 2 and 3 percent, respectively, relative to current technology should be achievable. These gains will result in fuel consumption improvements of 2 to 4 percent, depending on the actual improvements and engine cycles.

Currently, overall pressure ratios are greater than 25:1, and they may reach 40:1 by the year 2000. Projections for the fan and compressor stage loadings in the year 2000 time period are pressure ratios of 2:4 in one stage and 4:0 in two stages. The improvements will result in lighter engines and reduced fuel consumption.

### Combustors

Improved materials such as ceramics will allow higher average combustion temperatures by the year 2000 relative to the mid-1980's. Projections are that 3,200° F combustion temperatures would be available in the mid-1980's. Combustion temperature exceeding 3,200° F should be achievable in the late 1990's. However, at combustion temperatures in excess of 2,600° F, dissociation occurs, reducing the effective efficiency. Thus, trades of specific thrust and SFC versus combustion temperature are necessary.

Use of ceramics in the main burner and turbine will require careful design of the compressor inlet flow path so as to avoid ingestion of foreign objects which might impinge on ceramic material and cause cracking or chipping. Here again, 3-D analysis computer programs may be developed which should aid in obtaining good compressor inlet flow path designs.

### Turbines

Use of ceramics, particularly in engines for unmanned aircraft, will be demonstrated in the early 1980's. The extension of ceramics to manned engines is considered feasible for the time frame considered. Turbine inlet temperatures for uncooled ceramics will be limited to approximately 2400° F in the 1980's. However, cooled ceramic blades and vanes as well as supporting structures could allow further increases in turbine inlet temperature. Use of ceramics may allow operation of turbines in gas temperatures of 3,000° F with as little as 6-percent total turbine cooling flow.

Maximum turbine cooling flow temperatures are currently around 1,100° F for supersonic cruise conditions; projected 1985 temperatures are 1,200° F. A further increase to about 1,300° F may be expected for the year 2000.

### Augmenters

Current technology augmenters have peak efficiencies near maximum augmentation (fuel-air ratios greater than 0.06) of less than 90 percent.

Current augmenters tend to be nearly 4 feet long to achieve these efficiency levels. Swirl-can burners have recently been studied and tested which result in significantly higher efficiencies in shorter burner lengths (Reference 3). For example, peak combustion efficiencies of near 100 percent and efficiencies at high fuel-air ratios of 94 to 98 percent can be achieved in augmenters less than 2 feet long. The reduced length results in lighter weight and less required cooling flow (and, thus, higher maximum augmentation temperature and thrust).

## Cycles

Engine cycles which have been assessed include turbofans, variable-cycle engines, mixed mission integrated propulsion system (MMIPS), turboprops, regenerative and intercooled cycles, constant-volume combustion cycle, compound cycle, and rocket-assisted takeoff (RATO).

### Turbofans

Conventional mixed-flow turbofan engines provide low fuel consumption for subsonic cruise and low exhaust gas temperatures for low IR signature.

Current technology engines have thrust-to-weight ratios of from 7 to 8. Military engines currently being studied with technology availability dates in the early 1980's have thrust-to-weight ratios approaching 11 for conventional cycles. This advance, relative to current engines, is being achieved through improved materials, higher specific thrust, higher stage loadings (fewer stages), and shorter augmenters. Continued improvement in materials through the late 1990's will improve thrust-to-weight ratio still further. Improved turbine materials and improved component performance levels will also increase specific thrust. Thus, thrust-to-weight ratios may be expected to improve to about 12 in the late 1990's. Variable-cycle engines and engines designed for high-speed, low-level flight would be expected to have somewhat lower thrust-to-weight ratios, depending on the particular design.

### Variable-Cycle Engines (VCE)

Variable geometry turbine turbojets are currently being studied for application to ATS in the 1985 time period. Studies indicate that this cycle is very competitive with fixed-cycle turbofans and with variable-cycle turbofans in the ATS. However, for all-subsonic aircraft, turbofans will provide lower SFC.

One example of the advanced engines being studied at AiResearch and which could have application in the proposed study is a unique VCE concept. It takes advantage of a characteristic of the centrifugal compressor, which allows compressor flow to be modulated without decreasing pressure ratio.

Variable geometry components include the variable diffuser centrifugal compressor, variable nozzle high- and low-pressure turbines, and the variable exhaust nozzle. Use of this engine in a high-performance fighter resulted in an 8-percent decrease in takeoff gross weight and a 22-percent decrease in fuel required when compared to a conventional, advanced technology augmented turbofan.

VCE's such as the General Electric variable area bypass injector (VABI) and the Pratt & Whitney Aircraft variable steam control engine (VSCE) have been considered for fighters and transports. Both cycles provide reduced SFC for multimission aircraft by maintaining airflow at the intermediate power level down to approximately 50 percent of intermediate net thrust. This also reduces inlet spillage and nozzle/afterbody drags.

Multimission integrated propulsion system (MMIPS) has been investigated in several aircraft studies. These studies indicated that MMIPS is most promising in aircraft that have significant performance requirements at two or more significantly different flight conditions.

Turboprops

Recent engine manufacturers studies (References 4, 5, and 6) show that advanced turboprop engines may have significant performance advantages up to 0.8 M relative to advanced turbofans. The effect of alternate fuels on turboprops and turbofans will not be appreciably different and, in the interest of simplicity, the decision not to study turboprop versions was made.

Rocket-Assisted Takeoff (RATO)

RATO should be considered when penalties might otherwise be incurred by the necessity of sizing the engines to meet a takeoff requirement. Other factors to be considered include a logistics problem and the structural weight penalty for mounting. Use was not considered for this study.

Regenerative and Intercooling Cycles

Three concepts which have been considered are:

1. Regenerative: The high-pressure compressor discharge air is ducted through a heat exchanger in the turbine discharge gas to preheat the air prior to burning. This reduces specific fuel consumption. An additional advantage of this cycle is reduced IR signature due to lower exhaust gas temperature. Previous studies

(References 4, 5, and 6) show that the performance gains tend to be offset by heat exchanger weight and pressure losses. Therefore, this concept is not recommended.

2. Intercooling: Cooling between compressor stages (for example, using liquid hydrogen as a heat sink) reduces the amount of work done to reach a given pressure. A study by Garrett/AiResearch indicates that performance may be improved slightly relative to a nonintercooled turbofan system. Here again, performance gains tend to be offset by weight and pressure losses, so the concept is not recommended.

3. Turbine Cooling Flow Cooling: Cooling of turbine cooling flow (using fuel as a heat sink) results in lower amounts of cooling flow required and, thus, higher specific thrust. Garrett/AiResearch is currently evaluating such a system.

*Inlet Technologies*

The assessment of inlet concepts and technology candidates concentrated on the design requirements of the respective missions. Only modest improvements in inlet total pressure recovery are anticipated by 2000. Major improvements will be in the areas of reduced weight, drag, and inlet/engine control integration. For design speeds of 1.6 M or less, normal shock inlets and fixed two-dimensional (2-D) and semicone inlets provide pressure recovery as good or better than more complex variable inlets (usually used for higher design speeds) and are also lighter. Because the normal shock inlet is lightest, it will be used for the strategic strike concepts in this study.

Variable capture area, variable incidence inlets, such as are used on the F-15, provide better inlet/engine matching over wide variations in the flight regime than do fixed inlets, plus reduced drag and favorable pitching moments. This type of inlet might be used for the higher design speed designs of the air superiority and area interceptor missions.

Nozzle Technologies

Two nozzle types have been considered: conventional axisymmetric and assymetric (2-D). Nozzle concept and technology assessment are summarized in Table 1. Axisymmetric, convergent-divergent, independently variable exit area nozzles provide peak internal performance for all operating conditions. However, 2-D nozzles offer potential benefits in several areas. Significant benefits to the aircraft maneuver capability and takeoff/landing distance have recently been identified with in-flight thrust vectoring, thrust reversing, and supercirculation lift propulsive lift enhancement. These benefits can improve maneuver performance for aircraft having given control

surfaces sizes, or can result in smaller control surfaces with an attendant reduction in aircraft weight and drag for the same maneuver performance. These features are mechanically more easily applied to a 2-D nozzle than to their axisymmetric counterparts. Recent studies indicate weight reductions associated with 2-D nozzles incorporating thrust vectoring/reversing when compared to axisymmetric nozzles incorporating the same features. Analytical studies have also shown improved supercirculation lift for high-aspect-ratio (width/height) 2-D nozzle designs compared to the restricted circular shape of axisymmetric nozzles. In addition, drag for multiple-engine installations may be less because of cleaner aircraft lines.

Because the maneuver advantage of 2-D nozzles is maximized at subsonic speeds and the maneuver requirements for both the air superiority and area intercept missions are primarily supersonic, the 2-D nozzle advantage is much reduced, and lack of another driving parameter precludes the necessity of their use. Additionally, in order to eliminate other effects which are extraneous to those caused by the alternate fuels, it was chosen to use conventional axisymmetric nozzles throughout this study.

### Control Technology

The complexity of advanced aircraft and the required capability for multimode in-flight variation of the flying qualities to achieve a specific mission task dictate the use of advanced control concepts. Such a concept is the digital, fly-by-wire, flight/fire/propulsion integrated control system. Through a trim drag reduction, the incorporation of an integrated control system can provide significant fuel savings and a related increase in engine life. Implementation of this concept requires the development of synthesis and analysis techniques to allow rapid convergence on the optimum, or near optimum, control laws applicable to the specific mission, the various segments of the mission, and the integrated control subsystem components. Such concepts are needed for application to advanced programs such as the Air Force advanced tactical aircraft and for the innovative strategic aircraft. The concepts permit steady-state performance to be optimized without regard to conventional stability margins required for transients; the transients may be sensed and stability margins increased for the duration of the transient. Assessment of this control concept is summarized in Table 1.

The integrated fire/flight/propulsion control system concept will be included in the propulsion system performance analysis.

### Basepoint Engine Selection

The engines selected for basepoint vehicles are summarized in Table 2. These engines show the current technology baselines and the changes which result due to the application of selected advanced technologies.

TABLE 2. SELECTED ENGINE CYCLE

| | Air superiority and area intercept | | Strategic strike | |
|---|---|---|---|---|
| | Current technology | Year 2000 IOC | Current technology | Year 2000 IOC |
| Uninstalled sea-level static maximum power thrust, lb | 24,000 | 24,000 | 16,000 | 16,000 |
| Design airflow, lb/sec | 225 | 200 | 350 | 315 |
| Bypass ratio | 0.60 | 1.20 | 2.0 | 2.8 |
| Turbine temperature, ° F | 2,400 | 3,000 | 2,400 | 3,000 |
| Overall pressure ratio | 24 | 35 | 26 | 35 |
| Maximum diameter (at nozzle), in. | 48 | 44 | 49 | 45 |
| Overall length, in. | 190 | 170 | 85 (w/o nozzle) | 81 (w/o nozzle) |
| Total weight, lb | 3,050 | 2,000 | 2,600 | 1,600 |
| Capture area, sq in. | 950 | 850 | 1,600 | 1,440 |
| Fuel flow improvement | | | | |
| Max power | - | 10% | - | NA |
| Dry power | - | 7% | - | 10% |

Figure 6. Area intercept mission.

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MASS PROPERTIES TECHNOLOGIES

Technologies under consideration for the time period in question include the use of composites and advanced metallics for structures, improved propulsion systems (as previously covered), and improved avionics. Each of these areas is discussed in detail in the following paragraphs.

Structures

The structures (materials) considerations included the study of advanced composites materials and advanced metallics. Various Rockwell ATF and B-1 studies as well as Air Force-sponsored studies by other companies led to the results presented herein. Table 3 presents a compilation of some of these studies (Reference 10).

Composites

The use of composite material has been studied extensively in the recent past, and programs such as the Advanced Design Composite Aircraft (ADCA) have been aimed at an "all-composite" vehicle. Mixed material studies, however, show a 40- to 60-percent use to be a "best" compromise in terms of both cost and performance at this time. Because of the time frame involved and the mission dependency of the actual percentage value, a choice has been made. For this study, the weight savings of composites over metallics will be assumed to be a 55-percent use of composites, with a design "philosophy" adopted at the midpoint between the minimum cost and minimum weight curves presented in Figure 11. For reference sake, the values are tabulated in Table 4.

TABLE 3. COMPONENT PROGRAMS IN APPLICATION OF COMPOSITES TO AIRCRAFT STRUCTURES - COMPLETED AND CURRENT (1970)

| Component | Number of programs | Weight saving (%) |
|---|---|---|
| Wings | 11 | 9 to 15 |
| Fuselages | 5 | 19 to 25 |
| Stabilizers and stabilators | 10 | 15 to 25 |
| Fins and rudders | 5 | 20 to 35 |
| Slats and flaps | 8 | 22 to 47 |
| Speed brakes, fences, and fairings | 13 | 23 to 32 |
| Landing gear doors | 5 | 29 to 36 |
| Helicopter blades | 4 | |
| Helicopter and V/STOL shafts and hubs | 3 | 30 to 45 |
| Miscellaneous | 15 | |
| Total | 79 | |

dynamics of this effect are associated with the span loading of the wing.

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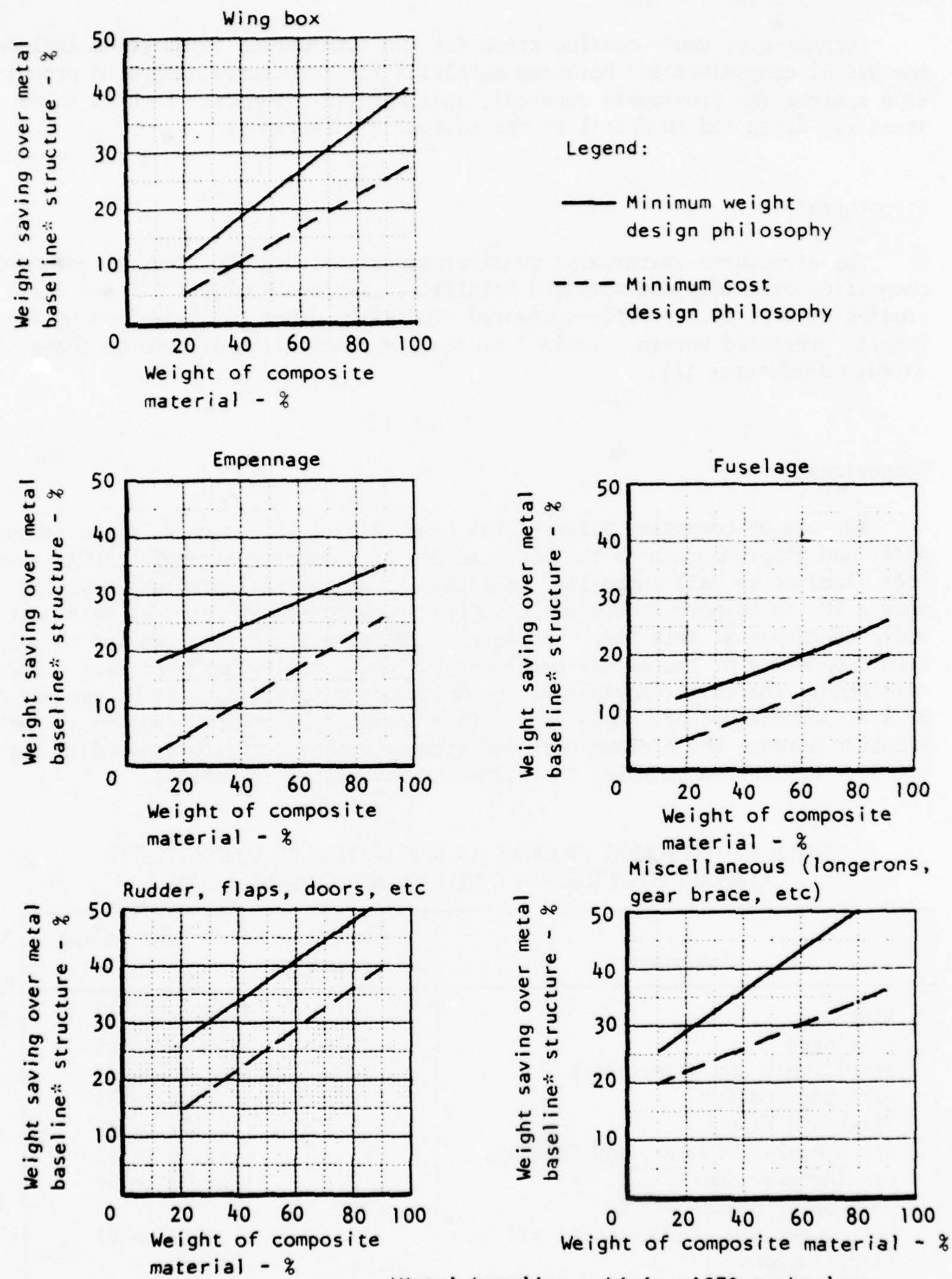



*Metal baseline vehicle, 1970 technology

Figure 11. Composite structure weight savings.

TABLE 4. COMPOSITE MATERIAL WEIGHT SAVINGS

| | |
|---|---|
| Wing box | 20% |
| Rudders, flaps, doors, etc. | 33% |
| Empennage | 21% |
| Fuselage | 15% |
| Longerons, gear boxes, etc | 35% |

These values have been used throughout this study wherever the use of composite materials is expected.

### Advanced Metallics

Advanced metallics studies have concentrated on the use of superplastic-formed, diffusion-bonded (SPF/DB) titanium. Structural studies such as those on the air-to-surface technology program (Reference 7) have shown current design methods have little or no payoff for lifting surface designs, but average approximately 24-percent weight svaings for fuselage weight savings, assuming 1986 material properties and primary structure only. Weight savings of 24-percent will be applied to fuselage primary structure for replacement by SPF/DB titanium designs.

### Materials Mix

Materials mixes will be determined from the mix supplied as baseline data and assuming advanced metallics and composites are used wherever applicable. Due to the results of studies mentioned in the preceding, advanced metallics will be used in the fuselage and composites elsewhere.

## AVIONICS TECHNOLOGIES

Trends relative to avionics installation have been developed (Figure 12) and will be used throughout the study. Baseline vehicle values will be used and factors will be applied to determine equivalent requirements for the modified baseline vehicles. Corrections will be applied only to the weights of modified inventory vehicles being studied.

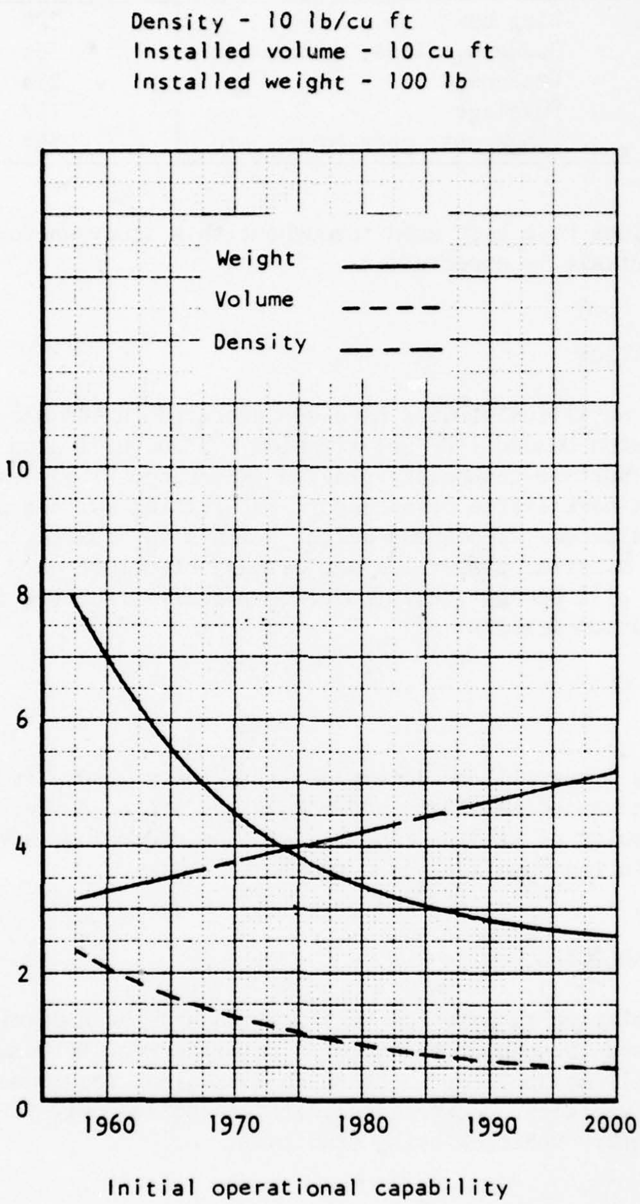



Figure 12. Avionics technology trends (typical).

## BASELINE SELECTION

The evaluation and selection of conventional fuel baseline vehicles were conducted in three phases: current technology vehicle modification, requirements evaluation, and baseline selection and verification. The technologies previously discussed were applied to the current technology baselines to estimate the characteristics of a year 2000 vehicle. This advanced technology vehicle was then parametrically varied to determine the effects of thrust loading and wing loading on mission requirements and was verified for the desired performance. Each class of vehicle (strategic strike and fighter-based) has its results discussed in the following paragraphs.

## CURRENT TECHNOLOGY VEHICLE MODIFICATION

### Mass Properties

Table 5 shows a summary of the baseline strategic strike vehicle weights estimate and compares it to the advanced technology version. The baseline vehicle is as supplied with the manufacturing variation removed from the structure. The advanced technology version has had composites and advanced metallics substituted in accordance with previously discussed assumptions. The propulsion system weight shows the effects of the advanced technology engines also described previously. The equipment groups show small reductions throughout the vehicle due to higher hydraulic system pressures, multiplex electrical, etc. Reductions in instruments and furnishings are due to an assumed reduction in crew size made possible by increased use of automated systems. The most significant item of the equipment groups is the avionics group weight. Trend development of avionics weight, volume, and density is only part of the statement of the problem. The overall trend in avionics has been an increase in requirements (or functions) such that the total system weight increases with time (Table 6 ). The system shown on the advanced technology baseline is a growth version of the B-1 avionics suite with the technology trend applied. The current technology vehicle is restricted to a 450,000-pound gross weight; therefore, with an assumed 50,000-pound payload, fuel must be off-loaded to a 223,000-pound total. As can be seen, if the same ground rule is applied to the advanced technology vehicle (i.e., design to a fixed gross weight), nearly 20 percent more fuel is available. The current technology basepoint is primarily an aluminum aircraft with over 76 percent of its structural weight of that material. An additional 12 percent of the weight is of steel, with the remainder spread in titanium, fiberglass, magnesium, etc. The smaller structural weight of the advanced technology vehicle results in one-half as much weight of aluminum, being equal to about 50 percent of the total. Graphite/epoxy makes up over 27 percent, with titanium and steel adding 7 and 8.5 percent, respectively. Fiberglass, aluminum honeycomb, graphite/epoxy honeycomb, and miscellaneous comprise the remaining 10 percent. These values for both vehicles are summarized in Table 7.

TABLE 5. STRIKE VEHICLE WEIGHT SUMMARY

| | Current Tech | W/Wo (%) | Advan Tech | W/Wo (%) |
|---|---|---|---|---|
| Structure group | (101,550) | 22.56 | (80,560) | 17.90 |
| Wing | 43,990 | | 34,800 | |
| Tail - Horizontal | 4,320 | | 3,490 | |
| - Vertical | 1,860 | | 1,560 | |
| Body | 27,460 | | 21,500 | |
| Alighting gear - Main | 12,450 | | 10,980 | |
| - Auxiliary | 1,070 | | 1,030 | |
| Engine section or nacelle | 9,940 | | 6,740 | |
| Air induction system | | | | |
| Arresting gear | 460 | | 460 | |
| Propulsion Group | (38,250) | 8.50 | (20,600) | 4.58 |
| Engine (as installed) | 31,320 | | 13,200 | |
| Accessory gear boxes and drives | - | | 800 | |
| Exhaust system | 420 | | 580 | |
| Cooling and drain provisions | 80 | | 80 | |
| Engine controls | 180 | | 100 | |
| Starting system | 390 | | 280 | |
| Fuel system | 5,860 | | 5,560 | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Equipment Groups | (30,450) | 6.77 | (27,340) | 6.07 |
| Flight controls | 2,750 | | 2,230 | |
| Auxiliary power plant | - | | - | |
| Instruments | 1,020 | | 760 | |
| Hydraulic and pneumatic | 2,020 | | 1,410 | |
| Electrical | 6,830 | | 6,210 | |
| Avionics | 9,830 | | 9,980 | |
| Armament | 4,550 | | 4,090 | |
| Furnishings and equipment | 2,230 | | 1,480 | |
| Air conditioning | 1,140 | | 1,100 | |
| Anti-icing | - | | - | |
| Photographic | 80 | | 80 | |
| Load and handling | | | | |
| Total weight empty | 170,250 | 37.83 | 128,500 | 28.55 |

TABLE 5. STRIKE VEHICLE WEIGHT SUMMARY (CONCL)

| | Current Tech | W/Wo (%) | Advan Tech | W/Wo (%) |
|---|---|---|---|---|
| Crew | 1,620 | (6) | 1,080 | (4) |
| Fuel - Unusable | 1,070 | | 1,070 | |
| - Usable | 223,000 | 49.55 | 266,440 | 59.20 |
| Oil - Engine | 730 | | 730 | |
| Passengers'/cargo | - | | | |
| Armament - bombs | 50,000 | 11.11 | 50,000 | 11.11 |
| - bomb prov | 800 | | 800 | |
| - guns | 270 | | - | |
| - ammo | 840 | | - | |
| - flares | 270 | | 270 | |
| Equipment - $O_2$ | 130 | | 90 | |
| - chaff | 1,020 | | 1,020 | |
| Total useful load | 279,750 | 62.17 | 321,500 | 71.45 |
| Takeoff gross weight | 450,000 | | 450,000 | |

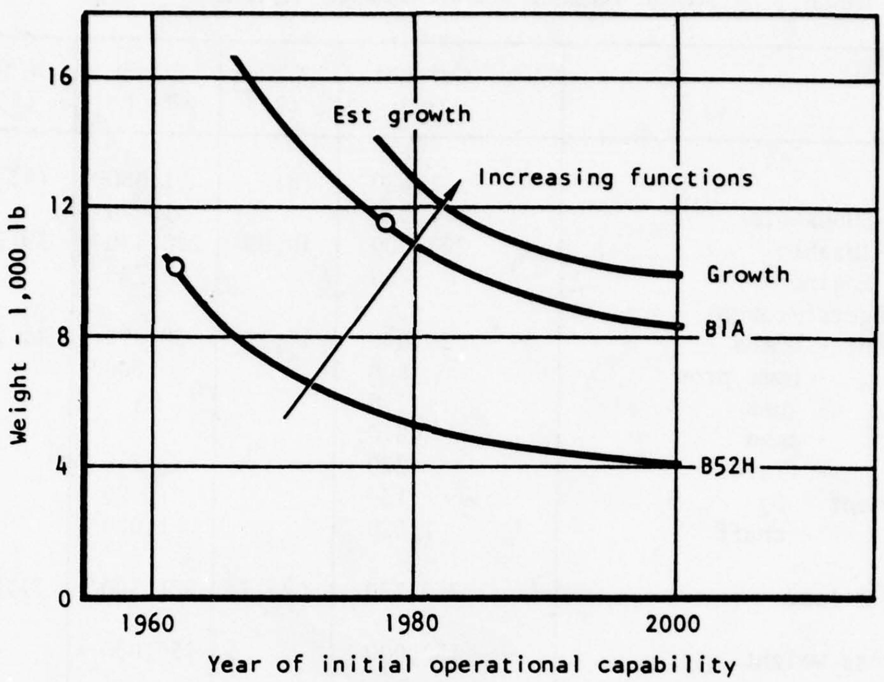



Figure 13. Avionics growth trends.

TABLE 6. AVIONICS GROWTH

| | | Vehicle | |
|---|---|---|---|
| Year | B-52H | B1A | Adv tech |
| 1962 | 9,926 | 20,500[a] | 24,500[a] |
| 1978 | 5,560 | 11,401 | 13,600[a] |
| 2000 | 4,000 | 8,350 | 9,976 |

[a]Extrapolated estimates

TABLE 7. MATERIALS MIX SUMMARY — STRATEGIC STRIKE VEHICLE

| | Current Technology | Advanced Technology |
|---|---|---|
| Structure - Total | 101,550 lb | 80,560 lb |
| - AMPR | 94,620 lb | 74,340 lb |
| | (Percent of AMPR) | |
| Aluminum | 76.7% | 48.9% |
| Titanium | 0.9 | 7.1 |
| Steel | 12.8 | 8.5 |
| Magnesium | 2.4 | --- |
| Graphite/epoxy | --- | 27.2 |
| Al honeycomb | 3.9 | 1.9 |
| G/E honeycomb | --- | 2.3 |
| Fiberglass | 1.3 | 1.7 |
| Others | 2.0 | 2.4 |
| Propulsion - Total | 38,250 lb | 20,600 lb |
| - AMPR | 5,810 lb | 6,550 lb |
| Equipment - Total | 30,450 lb | 27,340 lb |
| - AMPR | 20,800 lb | 17,680 lb |
| Weight empty | 170,250 lb | 128,500 lb |
| AMPR weight | 121,230 lb | 98,570 lb |

Table 8 shows a summary of the baseline air superiority and area interceptor weights and the corresponding advanced technology versions. The baseline vehicle is again as supplied, while the advanced technology versions incorporate composites and advanced metallics substituted. The propulsion system incorporates the advanced technology features also described in the previous discussion. The weight savings of these vehicles as compared to the baseline are not as large as the strike vehicle, due primarily to the latter technology used in the fighter baseline. Table 9 shows an estimated materials mix summary for each version. As can be seen, a high percentage of titanium is used in the current technology basepoint, but nearly one-half of the AMPR structural weight is aluminum. The advanced technology vehicle increases the percentage (but not the weight) of titanium used and reduces the aluminum through increased composite material. The resulting structural weight is approximately 15 percent lighter than the current technology version, and the total empty weight is over 18 percent less. The vehicle is volume limited; therefore, the fuel weight was not raised to hold the original takeoff gross weight, as was done on the strike vehicle. Armament was assumed to be four advanced short-range air-to-air missiles for the air superiority vehicle or four advanced long-range air-to-air missiles for the area interceptor. These missiles compare to current-day AIM-9 (Sidewinders) and AIM-7 (Sparrows). External stores drags of those missiles were assumed as equivalent to the advanced missiles.

## Aerodynamics

Aerodynamics trends for the advanced technology vehicles leads to the selection of reduced static stability (RSS) for all vehicles and a supercritical wing section for the strike vehicle. The reduced static stability margin leads to a reduction in trim drag and a small reduction in wetted area (due to a reduced horizontal tail size), while the supercritical wing allows a high penetration Mach number. Drag polars at 0.90 M at 50-foot altitude show these effects (Figure 14). The air superiority and area interceptor vehicles benefit from RSS and a variable camber wing. The variable camber feature allows the wing design to be "optimized" for both the subsonic cruise and maneuver points as well as the supersonic design conditions. A 0.90 M polar at 30,000-foot altitude compares the current technology against the variable camber section, noting a 1 G cruise condition and a 5 G maneuver condition (Figure 15). This figure does not show the benefit due to the high-acceleration cockpit. Although physiological benefits have been shown in previous studies, a primary benefit which results from use of the high-acceleration cockpit is a reduction of wave drag. A typical fighter of the F-15 class has approximately 20 percent of its wave drag due to the canopy, and reductions of 50 percent of that total are possible with forebody shaping and a high-acceleration cockpit design. A net reduction of 10 percent of total vehicle wave drag has been assumed for the advanced technology fighter baseline.

TABLE 8. FIGHTER VEHICLE WEIGHT SUMMARY

| | Current Tech Baseline | W/Wo (%) | Advan Tech Baseline | W/Wo (%) |
|---|---|---|---|---|
| Structure groups | (13,459) | 32.2 | (11,490) | 32.3 |
| Wing | 3,381 | | 2,700 | |
| Tail - horizontal | 617 | | 550 | |
| - vertical | 473 | | 420 | |
| Body | 6,029 | | 5,300 | |
| Alighting gear - main | 1,058 | | 970 | |
| - auxiliary | 250 | | 220 | |
| Engine section or nacelle | 102 | | 60 | |
| Air induction system | 1,437 | | 1,170 | |
| Arresting gear | 112 | | 100 | |
| Propulsion group | (6,916) | 16.6 | (5,000) | 14.1 |
| Engine (as installed) | 5,984 | | 4,120 | |
| Accessory gearboxes and drives | - | | - | |
| Exhaust system | - | | - | |
| Cooling and drain provisions | - | | - | |
| Engine controls | 36 | | 30 | |
| Starting system | - | | - | |
| Fuel system | 896 | | 850 | |
| Fan (as installed) | - | | - | |
| Hot gas duct system | - | | - | |
| Equipment groups | (6,107) | 14.7 | (5,110) | 14.4 |
| Flight controls | 788 | | 740 | |
| Auxiliary power plant | 464 | | 420 | |
| Instruments | 163 | | 120 | |
| Hydraulic and pneumatic | 429 | | 320 | |
| Electrical | 582 | | 520 | |
| Avionics | 1,659 | | 1,450 | |
| Armament | 731 | | 660 | |
| Furnishings and equipment | 269 | | 240 | |
| Air conditioning | 669 | | 640 | |
| Anti-icing | - | | - | |
| Photographic | - | | - | |
| Load and handling | 6 | | - | |
| Ballast and misc (man. tol.) | 347 | | - | |
| Total Weight empty | 26,482 | 63.5 | 21,600 | 60.8 |

TABLE 8. FIGHTER VEHICLE WEIGHT SUMMARY (CONCL)

| | Current Tech | W/Wo (%) | Advan Tech | W/Wo (%) |
|---|---|---|---|---|
| Crew | 215 | | 215 | |
| Fuel - unusable | 402 | | 400 | |
| - usable | 11,635 | 27.9 | 11,635 | 32.8 |
| Oil - engine | 76 | | 50 | |
| Passengers/cargo | - | | - | |
| Armament - M61 gun | 252 | | 200 | |
| - 940 rounds ammo | 531 | 1.3 | 530 | 1.5 |
| - missiles (4) | 2,040 | 4.9 | 800 | 2.3 |
| Equipment - parachute + survival kit | 62 | | 60 | |
| - lox + converter | 28 | | 20 | |
| Total useful load | 15,241 | 36.5 | 13,910 | 39.2 |
| Takeoff gross weight | 41,723 | | 35,510 | |
| Flight design gross weight | 37,400 | | 37,400 | |

NOTE: The interceptor version of the advanced technology baseline differs only in the armament weight carried (i.e., 2,000 versus 800 pounds) and, therefore, the takeoff gross weight (36,710 versus 35,510 pounds). All other systems weights are equivalent for both.

TABLE 9. MATERIALS MIX SUMMARY – FIGHTER VEHICLE

| | Current Technology Baseline | Advanced Technology Baseline |
|---|---|---|
| Structure - Total | 13,459 lb | 11,490 lb |
| --AMPR | 12,999 lb | 11,060 lb |
| | (Percent of AMPR) | |
| Aluminum | 47.3% | 30.0% |
| Titanium | 37.0 | 38.6 |
| Steel | 6.1 | 6.2 |
| Composite | 1.3 | 18.2 |
| Fiberglass | 0.9 | 1.5 |
| Others | 7.4 | 5.5 |
| Propulsion - Total | 6,916 lb | 5,000 lb |
| - AMPR | 722 lb | 690 lb |
| Equipment - Total | 6,107 lb | 5,110 lb |
| - AMPR | 4,124 lb | 3,290 lb |
| Weight empty | 26,482 lb | 21,600 lb |
| AMPR weight | 17,845 lb | 15,040 lb |

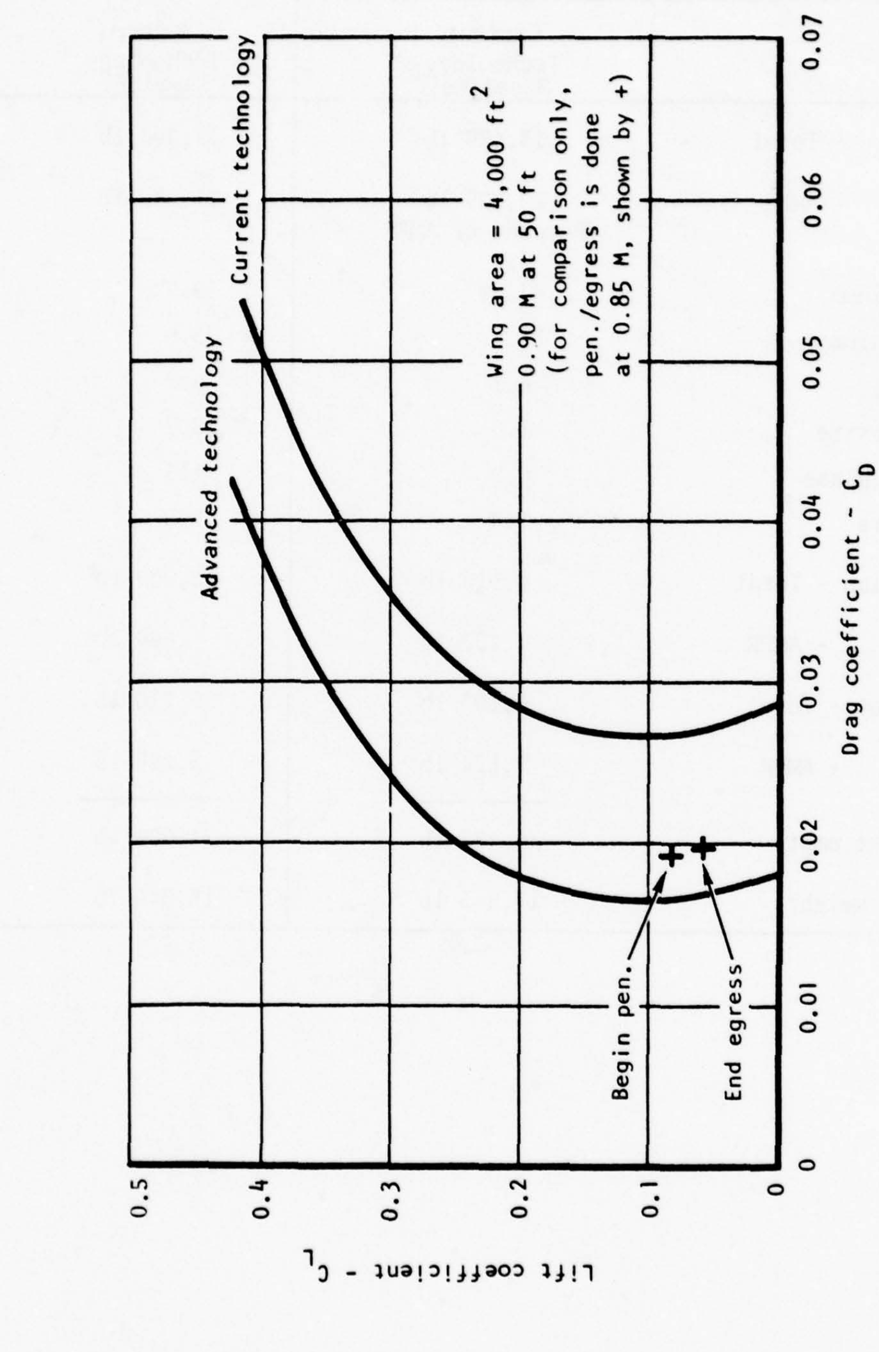



Figure 14. Strike vehicle penetration polars.

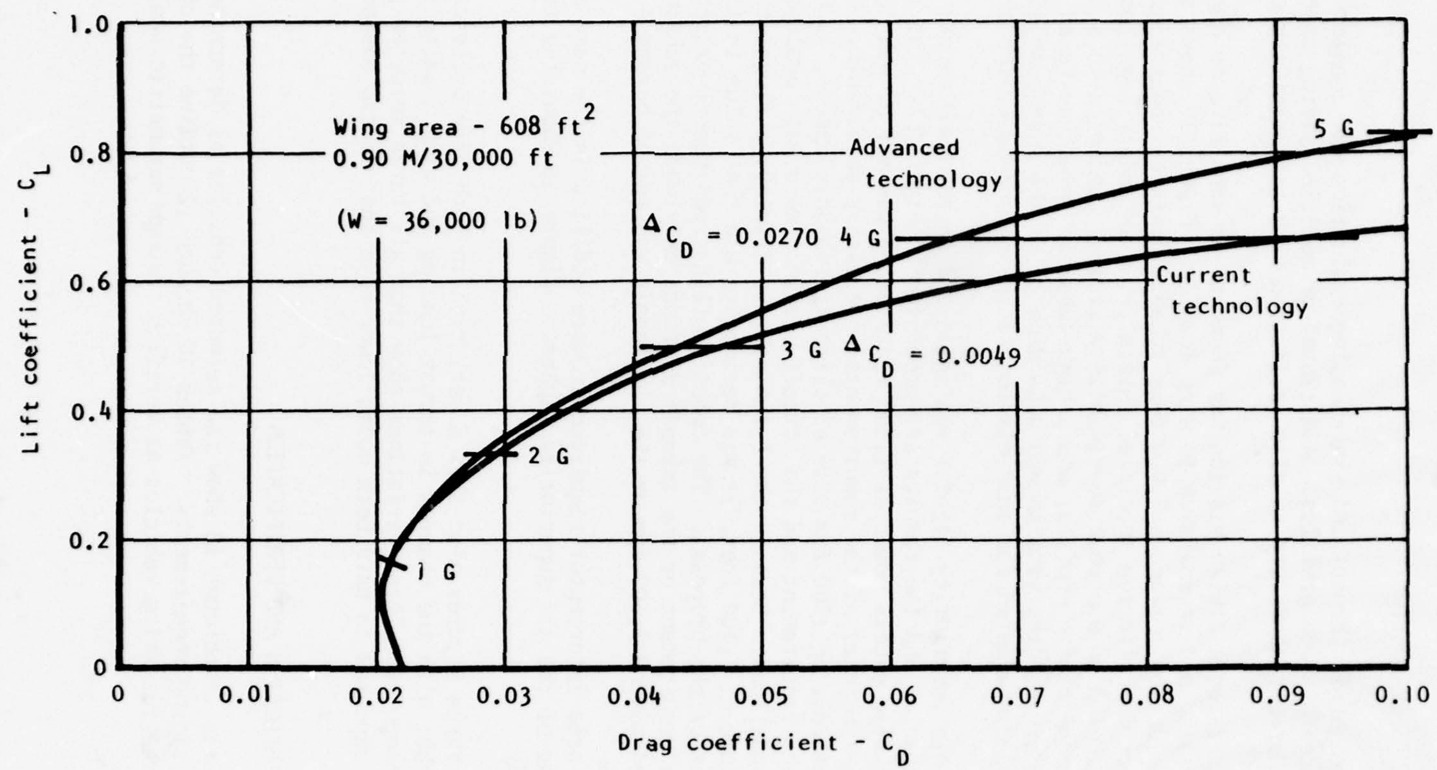



Figure 15. Air Superiority and interceptor maneuver polar.

## REQUIREMENTS EVALUATION

A parametric thrust- and wing-loading evaluation was completed for each of the three mission profiles. Additional or modified sizing criteria were adopted wherever necessary to allow selection of a basepoint study vehicle.

The strategic strike mission was found to be sensitive to changes in thrust loading and insensitive to wing loading. Figure 16 shows the results of the evaluation. Since a 7,000-foot takeoff distance requirement was the only selection criterion specified initially, a secondary requirement was generated based on numerous survivability studies conducted on a B-1 low-altitude penetration profile, and a high subsonic speed was found advantageous. Because these studies also showed 0.85 Mach to be the most cost effective, that speed was adopted for this mission as the second-selection criteria.

The air superiority fighter was optimized in the same manner as the strike vehicle, and the results are presented in Figure 17. The requirement for a specific excess power of 1,200 feet/second was met at sea level; however, the remainder of the requirements were easily attainable. Therefore, the combat ceiling (500 fpm rate of climb at subsonic speeds, 1,000 fpm at supersonic) requirement and the takeoff distance were both evaluated at more severe conditions. Because the F-15A vehicle displays a flight handbook takeoff distance of 1,500 feet, it was decided to use that value in lieu of the 5,000 feet of the proposal. The combat ceiling requirement exceeded the 1,200 fps requirement or the takeoff distance only when the subsonic value was raised beyond 2,500 fpm or the supersonic was raised beyond 4,500 fpm.

The area interceptor requirements were modified in the same manner as were those of the air superiority fighter. Figure 18 shows the results of this study.

All three figures also show a variation in both life cycle cost and flyaway cost with the changes in thrust loading and wing loading relative to the basepoint. These variations show that all three selected vehicles would be expected to have both costs lower than that of the basepoint.

## VEHICLE SELECTION AND VERIFICATION

Figures 16 through 18 show the selected vehicles as determined by the critical sizing requirements. Tables 10 through 12 outline the characteristics of the resulting vehicles as verified through parametric analyses.

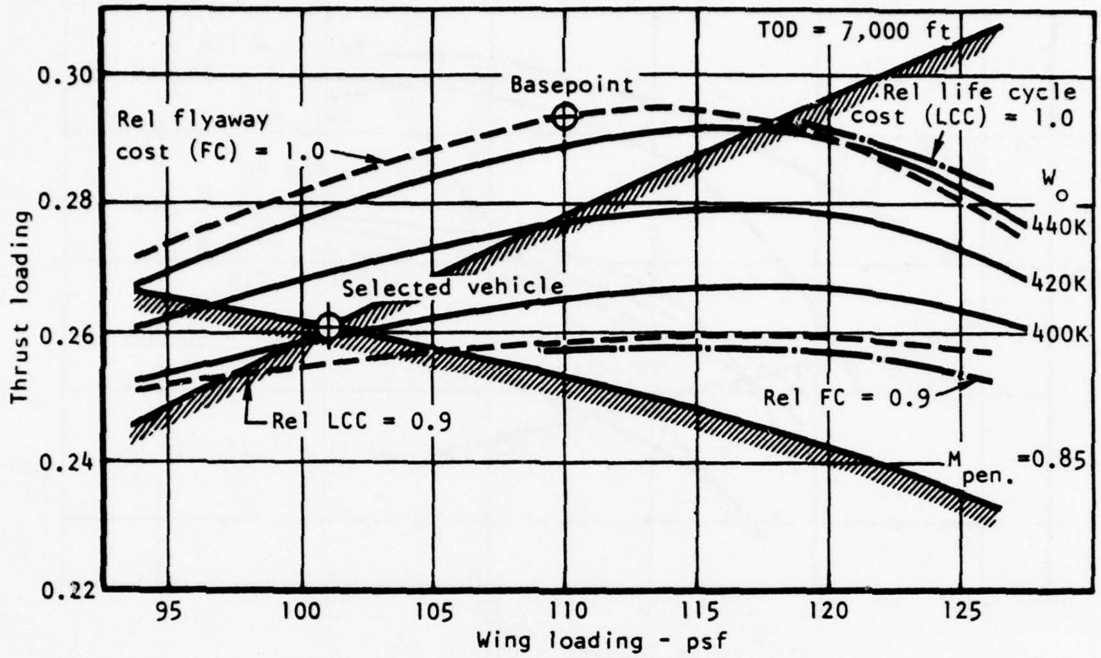



Figure 16. Strike vehicle selection.

TABLE 10. SELECTED VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 404,000 lb |
| Wing area | 4,000 sq ft |
| Wing loading (takeoff) | 101 psf |
| Propulsion system - 8 adv technology turbofans 13,200 lb thrust each (SLS, uninstalled) | |
| Thrust loading (takeoff) | 0.26 |
| Weight fuel | 239,133 lb |
| Weight payload | 50,000 lb |
| Penetration Mach number | 0.85 |

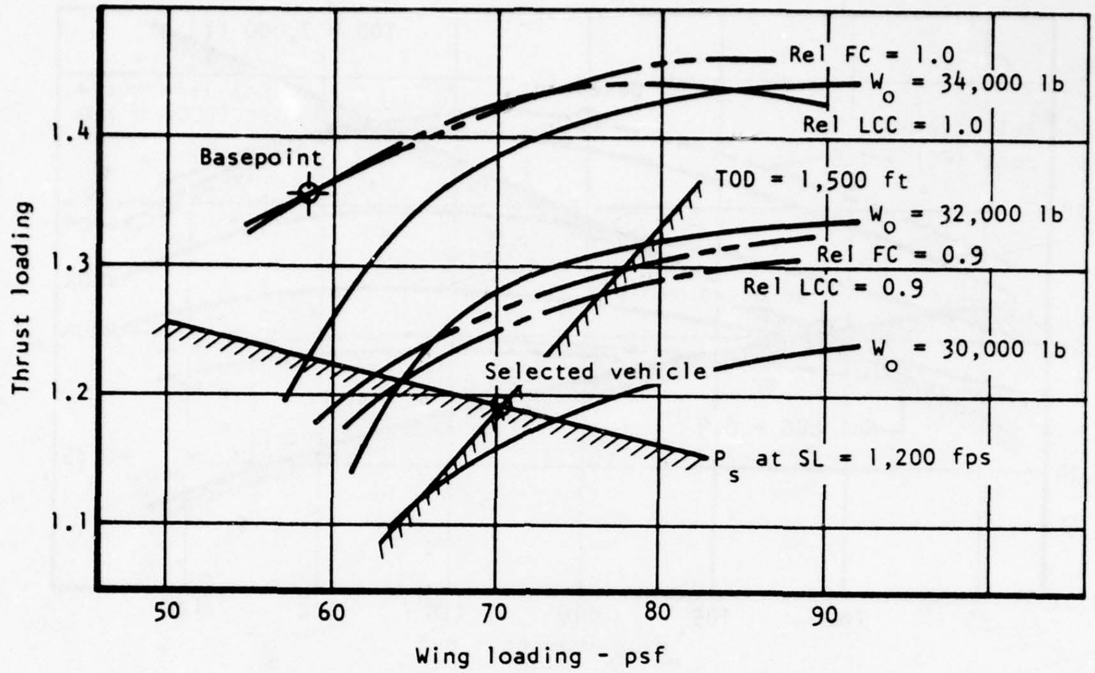



Figure 17. Air superiority vehicle selection.

TABLE 11. SELECTED AIR SUPERIORITY VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 30,700 lb |
| Wing area | 436 sq ft |
| Wing loading (takeoff) | 70.4 psf |
| Propulsion system - 2 adv technology turbofans 18,300 lb thrust each (SLS, uninstalled) | |
| Thrust loading (takeoff) | 1.19 |
| Weight fuel | 10,043 lb |
| Weight payload | 800 lb |

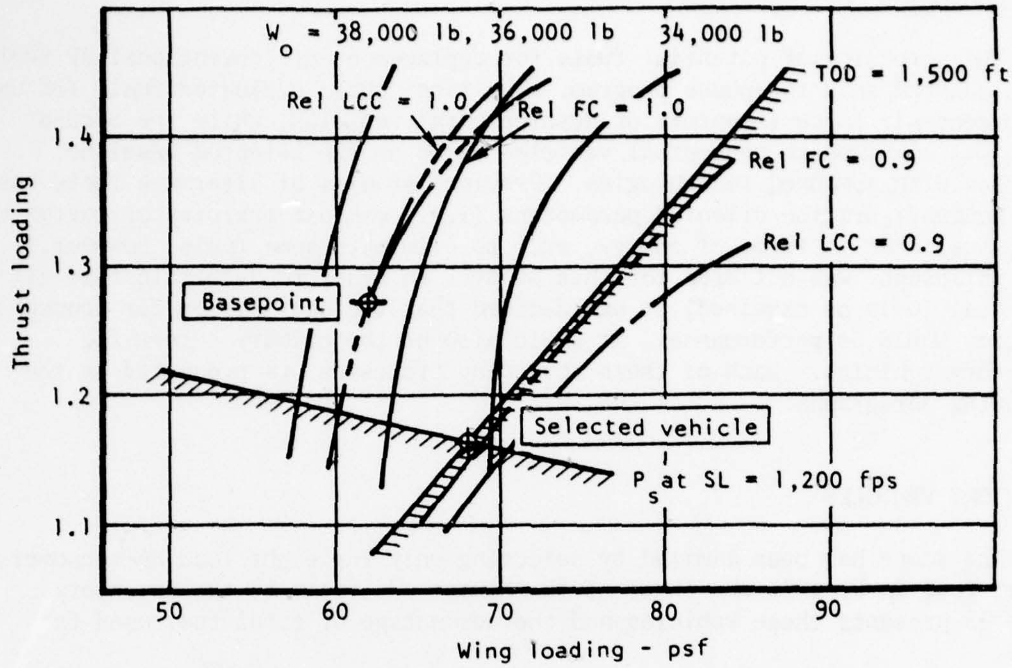



Figure 18. Area interceptor vehicle selection.

TABLE 12. SELECTED AREA INTERCEPTOR VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 34,250 lb |
| Wing area | 501 sq ft |
| Wing loading (takeoff) | 68.3 psf |
| Propulsion system - 2 adv technology turbofans 18,900 lb thrust each (SLS, uninstalled) | |
| Thrust loading (takeoff) | 1.16 |
| Weight fuel | 11,185 lb |
| Weight payload | 2,000 lb |

FUEL SCREENING AND SELECTION

The screening of potential fuels for replacement of conventional JP fuels was conducted in a two-phase program. The first phase evaluated fuels for use in current Air Force inventory or developmental vehicles, while the second phase was confined to conceptual vehicles based on the selected baseline vehicles with advanced technologies. Previous studies of alternate fuels have used nonconfiguration-oriented parameters (i.e., exhaust toxicity or corrosiveness, fuel cost in terms of energy, etc) to eliminate some fuels; however, that philosophy was not used for this study. In order to ascertain that all potential fuels be examined, it was decided that the only screen for conceptual vehicles would be performance. It would also be the primary screen for inventory vehicles. Each of these screening processes is presented in the following paragraphs.

INVENTORY VEHICLES

The scope has been limited by selecting only the eight leading consumers of jet fuel in FY 1975 and three of the newest additions to the inventory. Table 13 presents these vehicles and the percentage of total fuel used for FY 75.

TABLE 13. ALTERNATE FUEL CANDIDATE VEHICLES

| Vehicle | Fuel used (%) |
|---|---|
| C-141 | 15 |
| B-52 | 15 |
| F-4 | 15 |
| KC-135 | 12 |
| C-5 | 7 |
| C-130 | 7 |
| T-38 | 4 |
| F-111 | 3 |
| F-15 | New in inventory |
| F-16 | New in inventory |
| A-10 | New in inventory |

It has been assumed that a fixed fuel energy content of each vehicle is required to complete its design mission, and that unless some change in conversion efficiency is obtained, an energy total equal to that of JP-4 will be required. Therefore, the fuel volume available may be equated to vehicle performance and act as the primary fuel screen. Table 14 presents the energy density of the fuels being considered.

Standard aircraft characteristics (SAC) charts were used to determine the fuel quantity required for the design mission and the total fuel volume available (Table 15). A required energy density factor may be calculated by determining the energy required for the design mission (fuel quantity required times energy per pound) and dividing by the volume available. This methodology assumes a constant fuel energy requirement for the mission, and no external fuel tanks are considered. Comparison of the required energy density with the energy density available creates a preliminary screen. Table 16 shows the fuels/aircraft being considered and the results of this screening process. The letter "E" under the fuel indicates that the energy content is insufficient and no further consideration of the fuel will be made for that aircraft.

A secondary screen for these vehicles considered operational constraints and vehicle modifications required to use the alternate fuels.

The fuel feed problems associated with solid or powdered fuels and the separation of liquid hydrocarbon and powdered fuel slurries were considered as serious enough to preclude their use in inventory vehicles. These vehicles are denoted by the letter "S" in Table 16. They have also been eliminated from further consideration for each aircraft. Of the remaining fuels, acetylene, propane, methane, and silane have been eliminated by the low boiling points and the need for pressurized tanks for containment, as it was felt that an airframe modification program of the order required was not justified. The boron-based pentaborane and diborane fuels were eliminated as being incompatible with current inventory fuel systems due to their toxicity and (for pentaborane) spontaneous combustion properties. Ethanol has a heating value approximately one-third less than JP-4 on a per-unit weight basis, meaning that one-third more fuel (by weight) must be carried. This, in turn, reduces the payload capability of the C-130E by over 15,500 pounds (nearly equal to 35 percent) and the C-5A by over 85,000 pounds (nearly equal to 40 percent) and, therefore, eliminates ethanol from consideration. Syncrude heating value, by comparison, is approximately 4 percent less than JP, resulting in a small loss of payload for the design mission of each vehicle. The list of potential alternate fuels for inventory aircraft therefore consists only of "syncrudes" derived from oil shale, tar sands, or coal for any of the vehicles discussed. Because the characteristics of these fuels are so similar to JP-4, no further work was conducted on these inventory vehicles.

TABLE 14. ALTERNATE FUEL CANDIDATES
(RANKED BY ENERGY DENSITY)

| | |
|---|---|
| Boron | 3.66 million BTU/ft$^3$ |
| Beryllium | 2.90 |
| Titanium | 2.30 |
| Hydrogen (metallic) | 2.25 |
| Aluminum | 2.24 |
| Carbon | 1.98 |
| Silicone | 1.98 |
| Shelldyne (JP-9) | 1.20 (reference) |
| Magnesium | 1.15 |
| Pentaborane | 1.13 |
| JP-8 | 0.95 (reference |
| Kerosene | 0.94 (reference) |
| JP-8 | 0.94 |
| Syncrudes | 0.91 (reference) |
| JP-4 | ~0.91 |
| Lithium hydride | 0.88 |
| Acetylene | 0.80 |
| Gasoline | 0.80 (reference) |
| Silane | 0.73 |
| Propane | 0.72 |
| Ethanol | 0.63 |
| Lithium | 0.62 |
| Methane | 0.55 |
| Methanol | 0.42 |
| Ammonia | 0.30 |
| Hydrogen (slush) | 0.26 |
| Hydrogen (liquid) | 0.23 |

TABLE 15. FUELS ASSESSMENT (INVENTORY AIRCRAFT)

Energy content of fuel carried must be equivalent to energy content of design mission fuel required (SAC chart)

Internal fuel only (unless specified)

Design payload onboard

| Vehicle | Fuel volume available | Design mission fuel required | Energy factor required |
|---|---|---|---|
| B52H | 48,030 gal | 44,708 gal | 0.93 |
| KC135A | 31,200 | 30,018 (incl transfer) | 0.96 |
| C130E | 9,680 (w/fixed pylon) | 5,196 | 0.54 |
| C141A | 23,592 | 17,443 | 0.74 |
| C5A | 49,000 | 28,544 | 0.58 |
| T38A | 583 | 583 | 1.00 |
| F4E | 1,855 | 2,595 (w/ext tank) | 1.00 |
| F15A | 1,714 | 1,714 | 1.00 |
| F16A[a] | 1,002 | 883 | 0.88 |
| F111F | 5,035 | 6,235 (w/ext tank) | 1.00 |
| A10A | 1,638 | 1,638 | 1.00 |

[a]Estimate – No SAC chart data available.

TABLE 16. ALTERNATE FUELS ASSESSMENT

| A/C \ Fuel | Boron | Beryllium | Titanium | Hydrogen (metallic) | Aluminum | Carbon | Silicon | Magnesium | Pentaborane | JP-8 (ref) | JP-4 (ref) | Lithium hydride | Syncrudes | Diborane | Acetylene | Silane | Propane | Ethanol | Lithium | Methane | Methanol | Ammonia | Hydrogen (slush) | Hydrogen (liquid) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-52H | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| KC-135A | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| C-130E | S | — | — | * | — | — | — | S | | | | S | | | | | | | S | | E | — | — | E |
| C-141A | S | — | — | * | — | — | — | S | | | | S | | | | | E | — | — | — | — | — | — | E |
| C-5A | S | — | — | * | — | — | — | S | | | | S | | | | | | | S | | E | — | — | E |
| T-38A | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| F-4E | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| F-15A | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| F-16A | S | — | — | * | — | — | — | S | | | | S | | | | E | — | — | — | — | — | — | — | E |
| F-111F | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |
| A-10A | S | — | — | * | — | — | — | S | | | | S | | | E | — | — | — | — | — | — | — | — | E |

## CONCEPTUAL AIRCRAFT

The screening process for alternate fuels for conceptual aircraft uses methodology developed for a number of advanced technology assessment studies. Using sensitivities developed for thrust, drag, weight, and specific fuel consumption, a figure-of-merit was calculated to be equal for offsetting changes in two of the variables. The point on one side of this "breakeven" line would have positive benefit, and points on the other would result in a decrement. The point at the maximum distance from the line would have the largest benefit.

In order to calculate benefits or decrements for the alternate fuels, the following assumptions were made for configuration considerations:

1. Fuel impact on the vehicle may be measured in terms of propulsion requirements (SFC, weight), systems requirements (weight), and structural requirements (volume, wetted area, weight, and fuel density).
2. The propulsion system impact of weight is minimal due to a fixed airflow (thrust proportional to airflow) and resulting engine size.
3. Alternate fuel SFC varies inversely with heating value.
4. Systems impact is second order.
5. Volume requirements vary inversely with energy density (BTU/ft$^3$).
6. Drag due to skin friction varies directly with the vehicle wetted area, and wave drag varies directly with cross-sectional area.

Additional ground rules for fuel installation were assumed as follows:

1. All volumes assume 250 cu in. per installed gallon of fuel.
2. Liquid fuels in nonpressurized tanks use F-15A containment values of 1.19 lb/cu ft for protected (fuselage) tanks and 0.35 lb/cu ft for unprotected (wing) tanks.
3. Solid fuels are treated as nonpressurized liquids in a continuous tank.
4. Liquid fuels in pressure tanks use 1.0 lb/cu ft except for liquid hydrogen, which uses 4.0 lb/cu ft including insulation.

Based on these assumptions, the alternate fuels for each of the three missions (strike, air superiority, and area interceptor) were evaluated. The results are discussed in more detail in the following:

## Strategic Strike Vehicle

Figure 19 shows the trade-off lines which were generated for the strike vehicle values of weight versus specific fuel consumption and skin friction drag versus specific fuel consumption, respectively. As can be seen from the two curves, for fuels which have higher specific fuel consumption (lower heating values) than JP, the effects of weight is extremely sensitive, while the effect of drag is independent of SFC. Based on these curves, the choice of one of the hydrogen fuels (solid, slurry, or liquid) would seem obvious. The major problem concerning solid hydrogen (the question of stability without pressurization) resulted in its elimination, and the other two varieties are considered essentially equal. The result, therefore, was the choice of a liquid-fuel version which allows a "fall-back" position to the higher density slurry should boiloff become a major problem. The choice of the second fuel was not as obvious as the choice of hydrogen. Liquid pentaborane and diborane fuels and solid boron or beryllium fuels showed advantages over JP, with the diborane showing the highest advantages of the four. None of the four, however, promised improvements of the same magnitude as those of hydrogen, and therefore were not chosen. The only fuel considered which was not shown on the trade study was nuclear. The large weight fraction of fuel required for the selected JP-powered version (nearly 60 percent) made it possible to consider nuclear fuel for this vehicle. Nuclear-powered studies for the Innovative Strategic Aircraft Design Study (ISADS) (Reference 8) show that this fraction was sufficient to install a nuclear propulsion system and that the range for such a vehicle is then restricted by factors unrelated to fuel availability. These considerations led to the choice of nuclear fuel as the second choice for the strategic strike vehicle

## Air Superiority Vehicle

Figure 20 shows the trade-off lines for the air superiority vehicle skin friction drag, wave drag, and weight versus specific fuel consumption, respectively. The wave drag and skin friction drag sensitivities are approximately equal for improved SFC, but virtually no increase in wave drag can accompany an increased SFC. The weight versus SFC variation can be seen to be linear throughout the study range. The fuels choice would again indicate that metallic hydrogen would produce the lightest weight fighter; however, as previously stated, the characteristics of this material are unknown to an extent that it was not considered. The other two types of hydrogen are again essentially equal and are again a potential choice. The same choices also result from this trade: pentaborane and diborane as nearly equal choices, and boron or beryllium solids also as nearly equal.

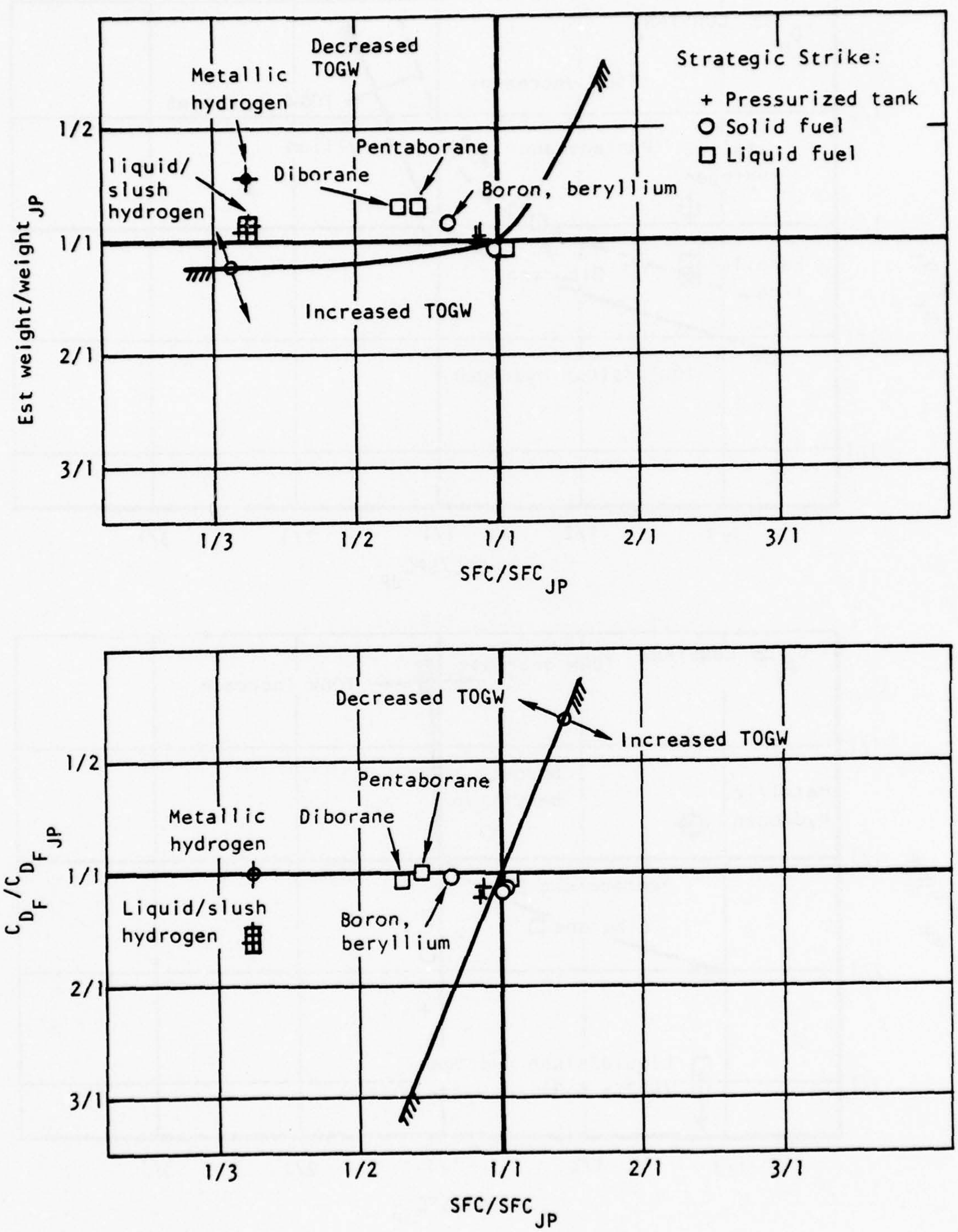



Figure 19. Strategic strike trade lines.

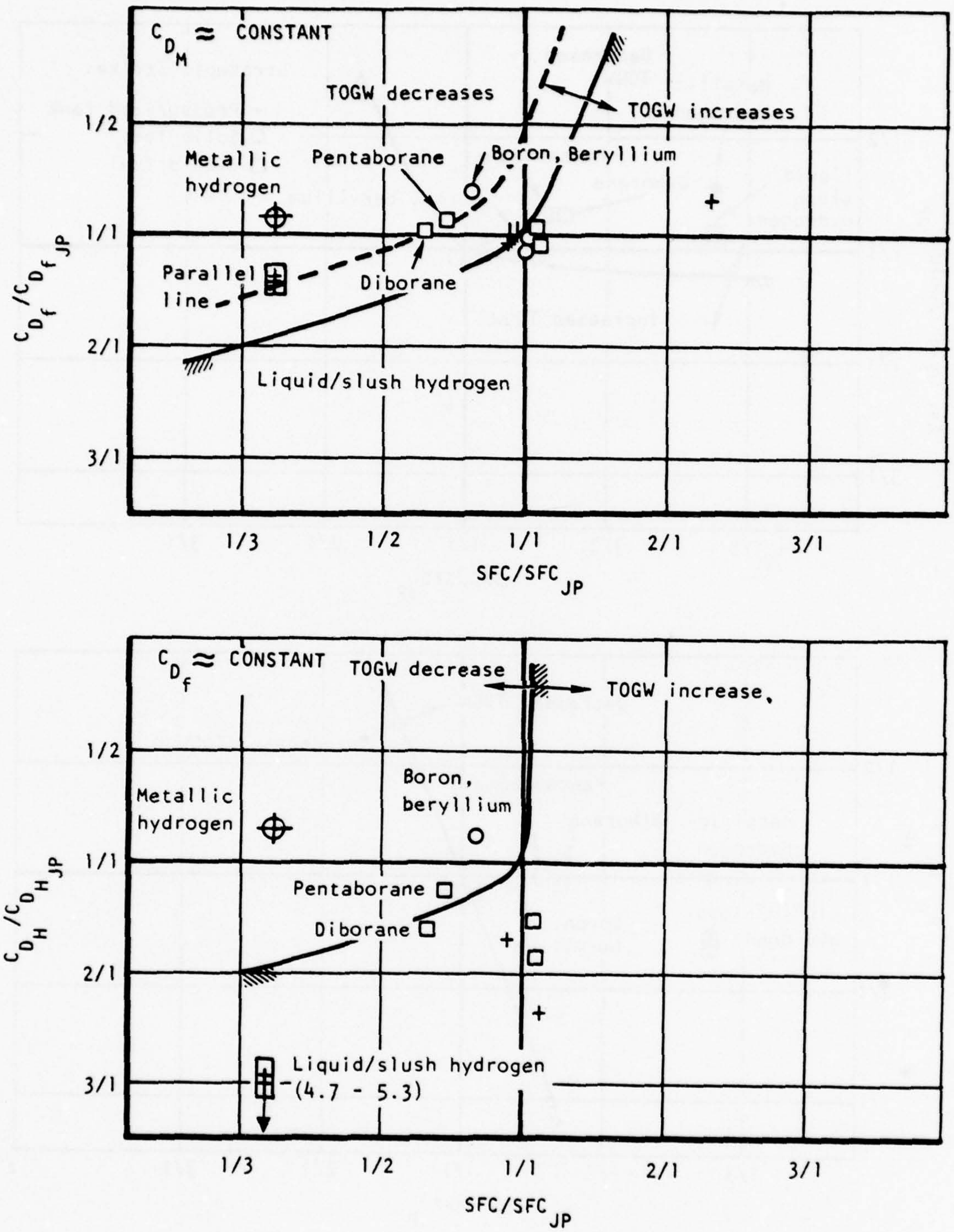



Figure 20. Air superiority trade lines

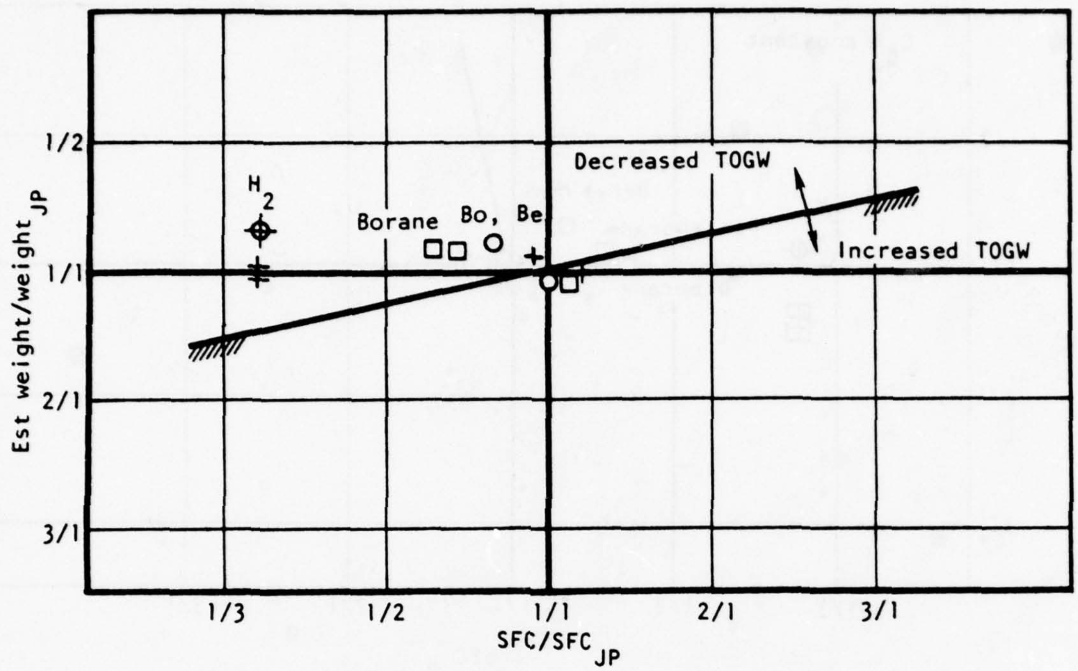
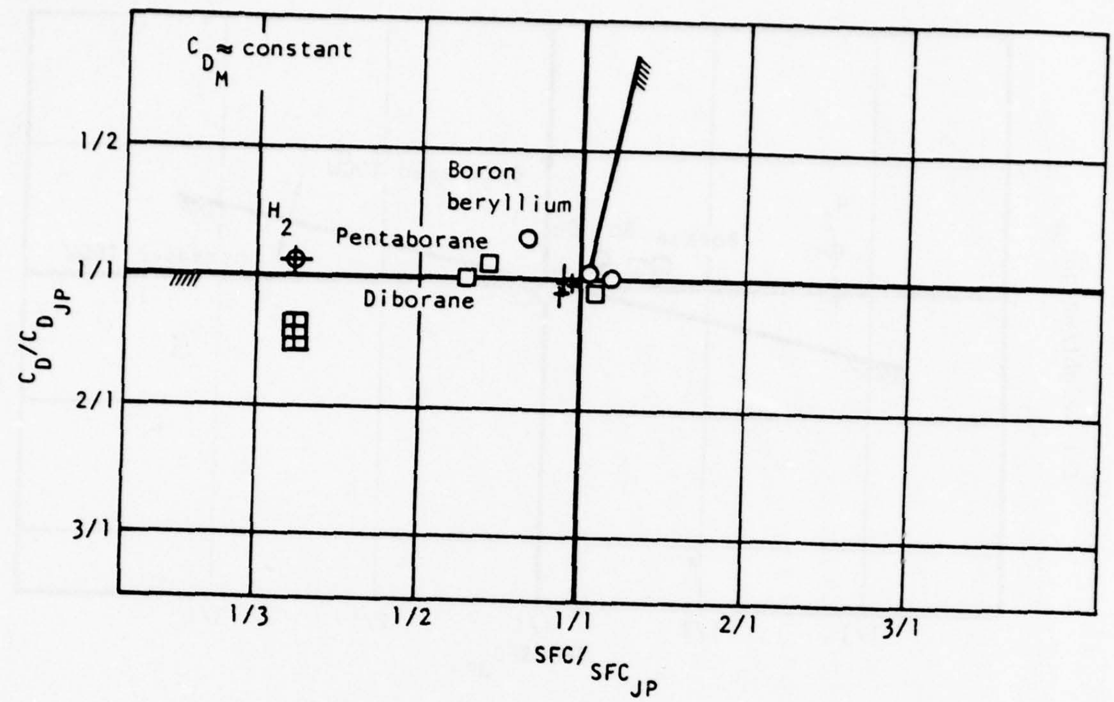



Figure 20. Air superiority trade lines (concl).

A more detailed analysis of requirements for a hydrogen-fueled air superiority fighter has resulted in the elimination of that concept. The trade lines shown are for changes in skin friction for nearly constant wave drag. The conceptual vehicle synthesized showed increases in wave drag could not be minimized as expected; therefore, this condition could not be met. The resulting combination of wave drag increase and skin friction increase caused this concept to be dropped from further study.

## Area Interceptor Vehicle

The results for the area interceptor fuel selection process are similar to those of the other two missions except for the hydrogen-fueled versions. For this mission, the liquid and slush hydrogen trades showed it not to be advantageous. The selected fuels would again include metallic hydrogen except for the stated problems and do include the borane fuels and boron and beryllium. These results are shown in Figure 21.



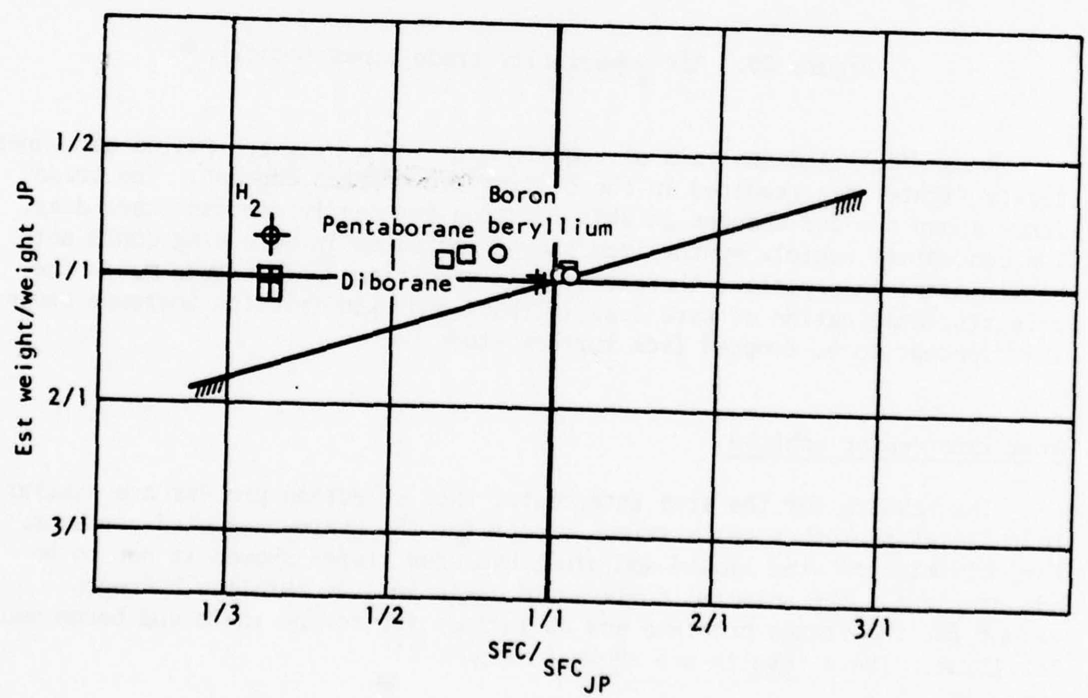




Figure 21. Area interceptor trade lines.

## Section III

## CONFIGURATION DEVELOPMENT

Following fuels selection and parametric development of a conventional fuel baseline vehicle, conceptual vehicles were configured to use these fuels. Using the sensitivities developed as the screening device, estimates of gross weight and fuel required were made and the selected vehicle thrust loading and wing loading were maintained. The conceptual vehicles were then developed to those parameters, and technical analyses were conducted on the resulting development.

The definition of configuration characteristics is presented in five parts: configuration design, mass properties, aerodynamics, propulsion, and performance.

### CONFIGURATION DESIGN

### STRATEGIC STRIKE AIRCRAFT

The two vehicles configured for this mission use nuclear and hydrogen fuels and result, therefore, in dissimilar designs which are surprisingly similar in many respects. Based on the JP-powered basepoint design, the thrust loading and wing loading were selected as 0.26 lb/lb and 101 psf, respectively. A preliminary estimate for each vehicle indicated that both should be lighter than the JP-powered version, and a target weight of 380,000 pounds was established using the change in fuel weight and propulsion system weight as the primary savings. Some details of each vehicle are presented in the following paragraphs.

#### Nuclear-Powered

Previous studies have shown heat from nuclear reactors could be used to power aircraft engines and be competitive with conventionally powered aircraft. With a vigorous research and development program, the necessary technology could be made available for a strategic aircraft with an IOC in the year 2000.

It was found from other studies of very large aircraft (Reference 1) that use of JP fuel for an emergency range capability and for takeoff and landing with the reactor inoperative for safety reasons severely penalized the

nuclear-powered aircraft. These aircraft were as much as 80-percent heavier than a conventional aircraft, and they carried as much as 65 percent of the JP fuel of the conventional aircraft. Containment of the reactor system elements has been demonstrated (Reference 9 ), and it is therefore believed practical to use the reactor power during takeoff and landing. Thus, a configuration with two reactors (to supply reactor-out flying capability) and no JP fuel was selected.

The following are some details of the propulsion system selected. Areas where further study should result in reduced vehicle weight and cost have been identified.

Engine Cycle. In an attempt to minimize engine size, a relatively high turbine inlet temperature of 2,400° F was selected. Current studies of nuclear power in space applications are using high-pressure helium as the reactor coolant with helium temperatures in excess of 2,400° F. This temperature also coincides with the projected maximum temperature for uncooled turbines. A high overall pressure ratio of 25 was selected to minimize heat exchanger volume and weight. A moderate bypass ratio of 2.8 was selected to minimize heat exchanger size and to allow a reasonable thrust/drag match at the mach 0.85 penetration. Engine characteristics are summarized in Table 17.

TABLE 17. MF78-03 ENGINE CHARACTERISTICS

| | |
|---|---|
| Sea-level static, maximum power thrust, lb (uninstalled | 16,000 |
| Design airflow, lb/sec | 315 |
| Bypass ratio | 2.8 |
| Combustor discharge temperature, ° F | 2,400 |
| Overall pressure ratio | 25 |
| Maximum diameter (at nozzle), in. | 50 |
| Overall length, in. | 81 |
| Dry weight, lb | 2,000 |

Reactor and Shielding. Results from previous studies were adapted and reactor power and dimensions were determined. Several approaches to shielding were previously examined, and unit shields (with all shielding around the reactor) were quickly eliminated from consideration because of excessive weight penalties. A range of aircraft crew and ground crew and ground crew dose rates were examined with and without shield augmentation (adding shielding around the reactor) while the aircraft was on the ground, and an augmented shield was adapted.

The resulting aircraft crew dose rate was selected as 5 mr/hr, while ground crew dose rates for 30 minutes after reactor shutdown at a distance at 20 feet from the center of the reactors were selected to be equal to the crew. In all cases, airport personnel at a distance of one-half mile during takeoff would receive less than 5 mr/hr.

The shield augmentation would require some special handling procedures. The reactor shield would be designed in a shell such that material such as mercury, lead shot, or steel shot could be "poured" into the shell and surround the reactor. The augmentation material could then be removed just prior to flight. While some special handling is required for this concept, it does provide an aircraft with essentially infinite-range/duration capability with a takeoff gross weight competitive to the baseline aircraft.

Aircraft Propulsion Improvements. During the trade study, several areas were identified where refinements could be made to reduce the aircraft gross weight.

It was found that if the aircraft drag characteristics were such that an engine cycle with higher bypass ratio or lower turbine inlet temperature could be used, a large impact on the heat exchanger weight and volume would result. For example, changing turbine inlet temperature from 2,400° to 2,200° F with a crosscounter flow heat exchanger would result in a large reduction in heat exchanger weight. Turbine inlet temperature reduction would aid in selecting and cost of the helium ducting. Helium flow rate also has a large impact on heat exchanger weight. Other parameters which affect heat exchanger and engine weights include compressor discharge temperature and pressure, air-side heat exchanger pressure loss, and helium-side heat exchanger pressure loss. Thus, significant improvements in the total propulsion system would be expected with additional effort in these areas.

Aircraft thrust-to-weight and wing-loading ratios were held at the baseline values for this trade study. Reoptimization of these parameters with the new engine characteristics should result in vehicle weight improvements. Additionally, a relaxation of takeoff distance from 7,000 to 8,000 or 10,000 feet would reduce weight still further. However, it was felt that

verification of the aforementioned potential improvements would be beyond the scope of this study, and the baseline nuclear system would be used for this study. A parametric variation in nuclear powerplant sizing was developed and is included as Appendix A.

Using the estimated weights and the parametric sizing methodology, a vehicle configuration was defined. This vehicle is shown as Figure 22.

Hydrogen-Powered

The hydrogen-powered strike vehicle is shown in Figure 23. This vehicle uses a Dewars type of tank for the fuel but is not pressurized, thereby allowing cutouts for missile bays, landing gear, etc, at some increase of volume required due to lower fuel density resulting.

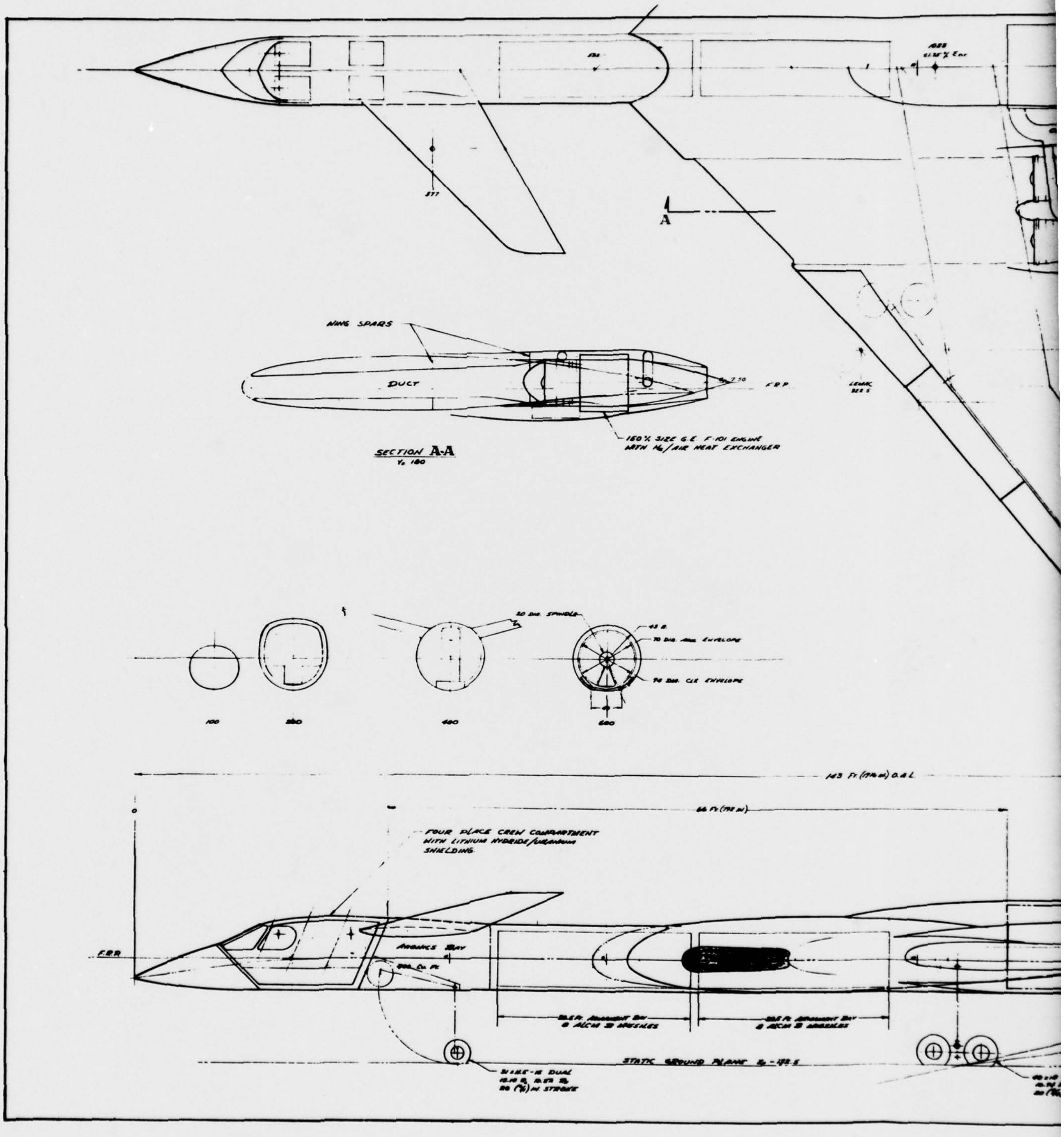
Air Superiority Vehicles

The estimated weights for the air superiority vehicles were also based on the thrust loading and wing loading of the selected JP-fueled basepoint. Fuel and estimated systems weights savings result in a weight of approximately 26,000 pounds for any of the borane fuels, borox or beryllium. Figure 24 shows the first of these fighters, which is configured for pentaborane fuel.

The second vehicle was designed to the same takeoff gross weight, wing loading, and thrust loading but used a solid boron or beryllium fuel rather than a liquid (diborane/pentaborane). Figure 25 presents the resulting vehicle, which is over 8 feet shorter due to the higher density of fuel. This vehicle concept shows "hopper-type" fuel tanks for the powdered fuel and would be expected to have an air bag or similar device to maintain positive fuel feed for inverted flight. This tankage scheme does not yield the efficiency for internal arrangement of liquid fuels; however, the difference in volume required appears to be more than compensating. The remaining systems are identical in performance to the conventional-fueled basepoint.

Area Interceptors

As with the other vehicles, the area interceptors using alternate fuels were synthesized prior to configuration development. These vehicles use the pentaborane or diborane liquid fuels for one version and the boron- or beryllium-powdered fuels for the second. Both are estimated to weigh about 29,000 pounds using the JP-fueled thrust loading and wing loading.



WING SPARS
DUCT
F.R.P.
160% SIZE G.E. F-101 ENGINE
WITH $H_2$/AIR HEAT EXCHANGER
SECTION A-A
A
100
400
600
143 FT (1716 IN) O.A.L.
FOUR PLACE CREW COMPARTMENT
WITH LITHIUM HYDRIDE/URANIUM
SHIELDING
AVIONICS BAY
F.R.P.
STATIC GROUND PLANE

2

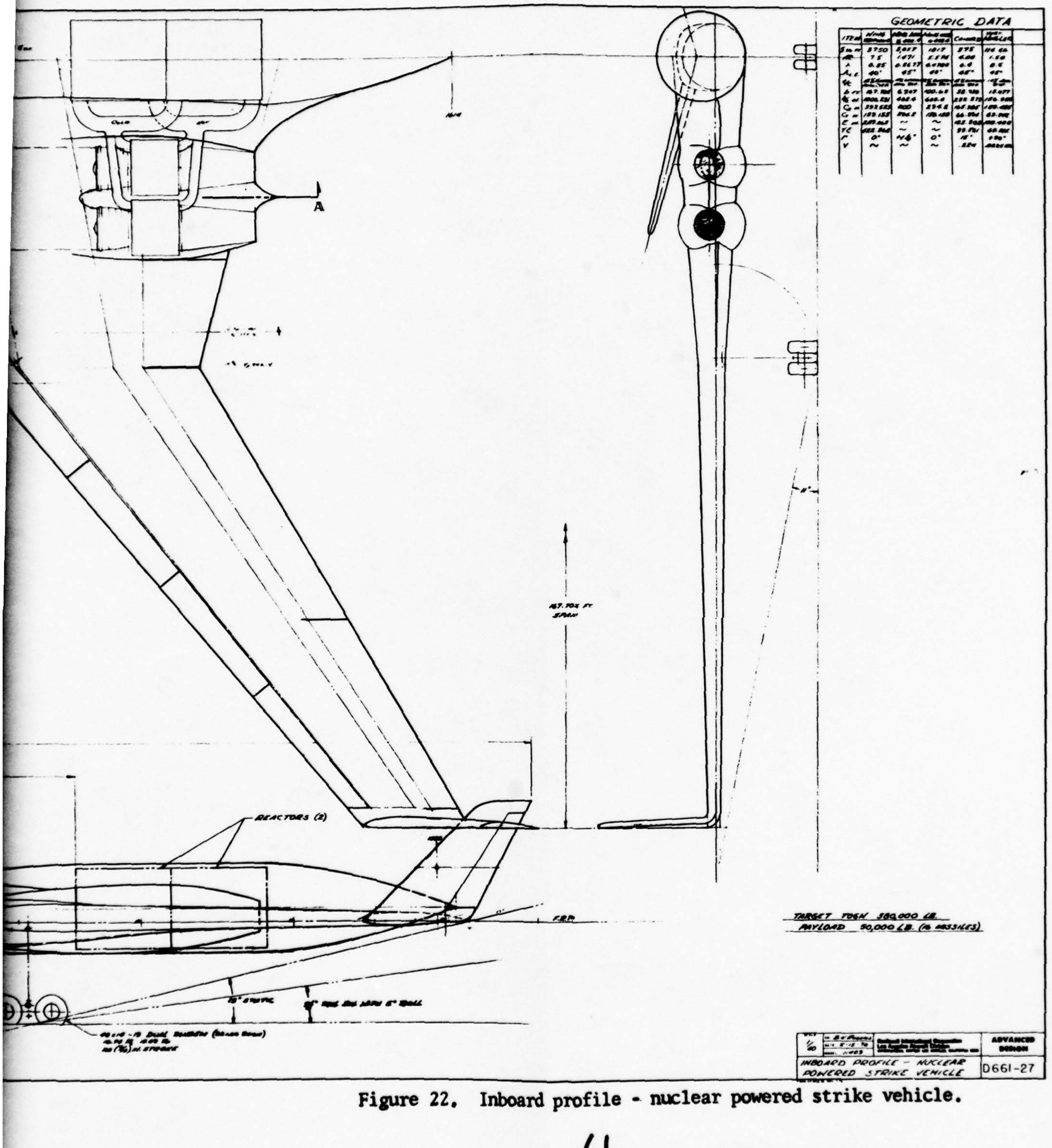
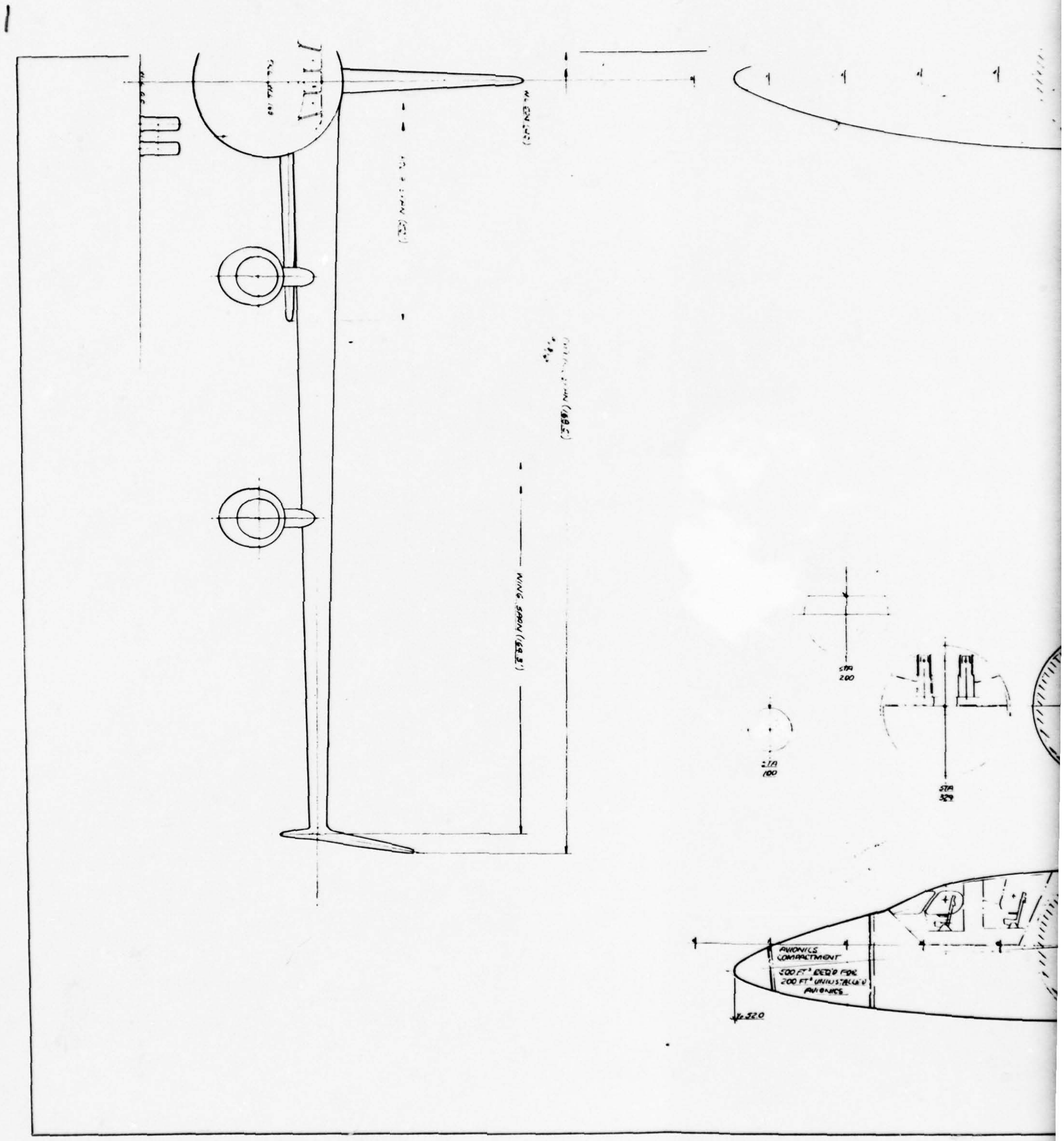
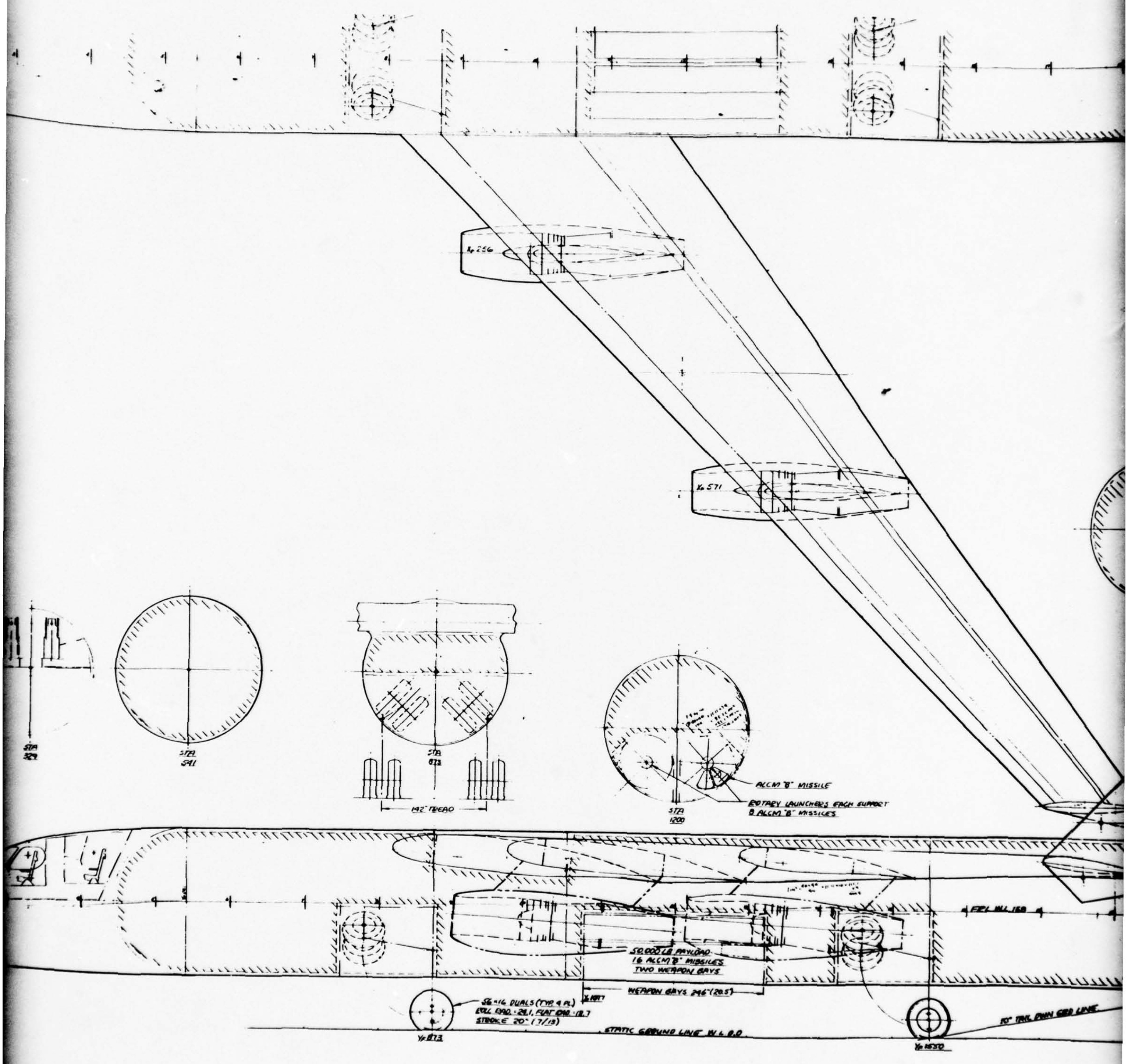



Figure 22. Inboard profile - nuclear powered strike vehicle.

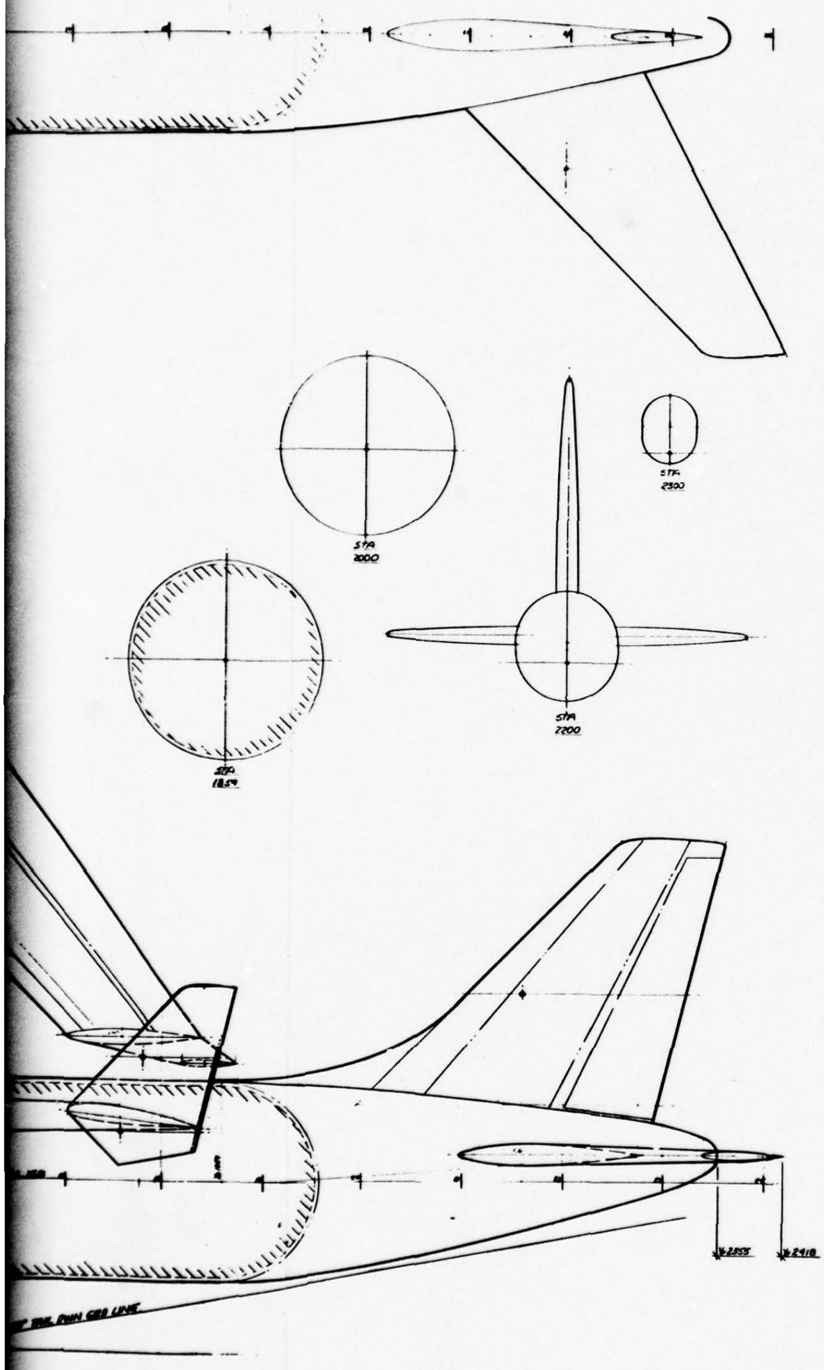


WING SPAN (169.8')
STA 100
STA 200
STA 329
AVIONICS COMPARTMENT
500 FT³ REQ'D FOR 200 FT³ UNINSTALLED AVIONICS

2



Y= 256
Y= 571
STA 529
STA 541
STA 873
142" TREAD
STA 1200
ALCM "B" MISSILE
ROTARY LAUNCHERS EACH SUPPORT 8 ALCM "B" MISSILES
FRL W.L. 160
50,000 LB PAYLOAD
16 ALCM "B" MISSILES
TWO WEAPON BAYS
WEAPON BAYS 246" (20.5')
56×16 DUALS (TYP 4 PL)
ROLL RAD. = 24.1, FLAT RAD. = 12.7
STROKE 20" (7/13)
STATIC GROUND LINE W.L. 0.0
Y= 873
Y= 1550
10° TAIL BUMP GRD LINE




GEOMETRIC DATA

| ITEM | WING | HORIZ. | VERT. | WING TIP ... UPPER |
|---|---|---|---|---|
| S $ft^2$ | 3600 | 667 | 268 | 80 SA |
| AR | 7.5 | 4.0 | 1.3 | 1.3 |
| λ | 0.35 | 0.35 | 0.35 | 0.35 |
| $\Lambda_{L.E.}$ ° | 45° | 45° | 45° | 45° |
| INCIDENCE ° | 6° | 0° | ——— | ——— |
| AIRFOIL | 12% SUPERCRITICAL | 12% t/c | 12% t/c | 12% t/c |
| b IN. | 1971.8 | 629.4 | 223.9 | 122.4 |
| $C_R$ IN. | 394.5 | 251.5 | 255.3 | 139.5 |
| $C_T$ IN. | 136.3 | 80.4 | 84.3 | 48.8 |
| $\bar{c}$ IN. | 283.2 | 168.2 | 185.6 | 101.4 |
| $C_{R}$ or $C_{BV}$ IN. | 412.8 | 131.1 | 94.0 | 51.4 |
| $l_H$ or $l_V$ IN. | ——— | 996 | 960 | 591 |
| V | ——— | 0.66 | 0036 | 0.013 (each) |

PROPULSION: FOUR (4) 150% SIZE GE F101 DRY ENGINES.
82,000 LB LIQUID HYDROGEN FUEL STORED AT 1 ATMOS PRESS ...
TANK (FUSELAGE WALL CONSTRUCTED OF 3 LAYERS OF SPF/...
2" THICK WITH 2" THICK INSULATION.

TARGET WEIGHTS: T.O.G.W. = 365,000 LBS
FUEL WT = 82,000 LBS
PAYLOAD WT = 50,000 LBS (16 ALCM "B" MISSILES)

Figure 23. Inboard profile - liqui

4

GEOMETRIC DATA

| ITEM | WING | HORIZ | VERT | WING TIP VERT. UPPER | WING TIP VERT. LOWER |
|---|---|---|---|---|---|
| S FT² | 3600 | 667 | 268 | 80 EA | 35 EA |
| AR | 7.5 | 4.0 | 1.3 | 1.3 | 0.92 |
| λ | 0.35 | 0.35 | 0.35 | 0.35 | 0.57 |
| $\Lambda_{LE}$ ° | 45° | 45° | 45° | 45° | 45° |
| INCIDENCE ° | 6° | 0° | ——— | ——— | 80° DIHEDRAL |
| AIRFOIL | 12% SUPERCRITICAL | 12% t/c | 12% t/c | 12% t/c | 12% t/c |
| b IN | 1971.8 | 624.4 | 223.9 | 122.4 | 46.0 |
| $C_R$ IN | 399.5 | 231.3 | 255.3 | 139.5 | 139.5 |
| $C_T$ IN | 136.3 | 80.4 | 84.3 | 48.8 | 79.5 |
| $\bar{c}$ IN | 283.2 | 168.2 | 185.6 | 101.9 | 112.3 |
| $\bar{c}_H$ OR $\bar{c}_V$ IN | 412.8 | 131.1 | 94.0 | 51.4 | 20.9 |
| $l_H$ OR $l_V$ IN | ——— | 996 | 960 | 591 | 557 |
| V̄ | ——— | 0.66 | 0.036 | 0.013 (TWO) | 0.0055 (TWO) |

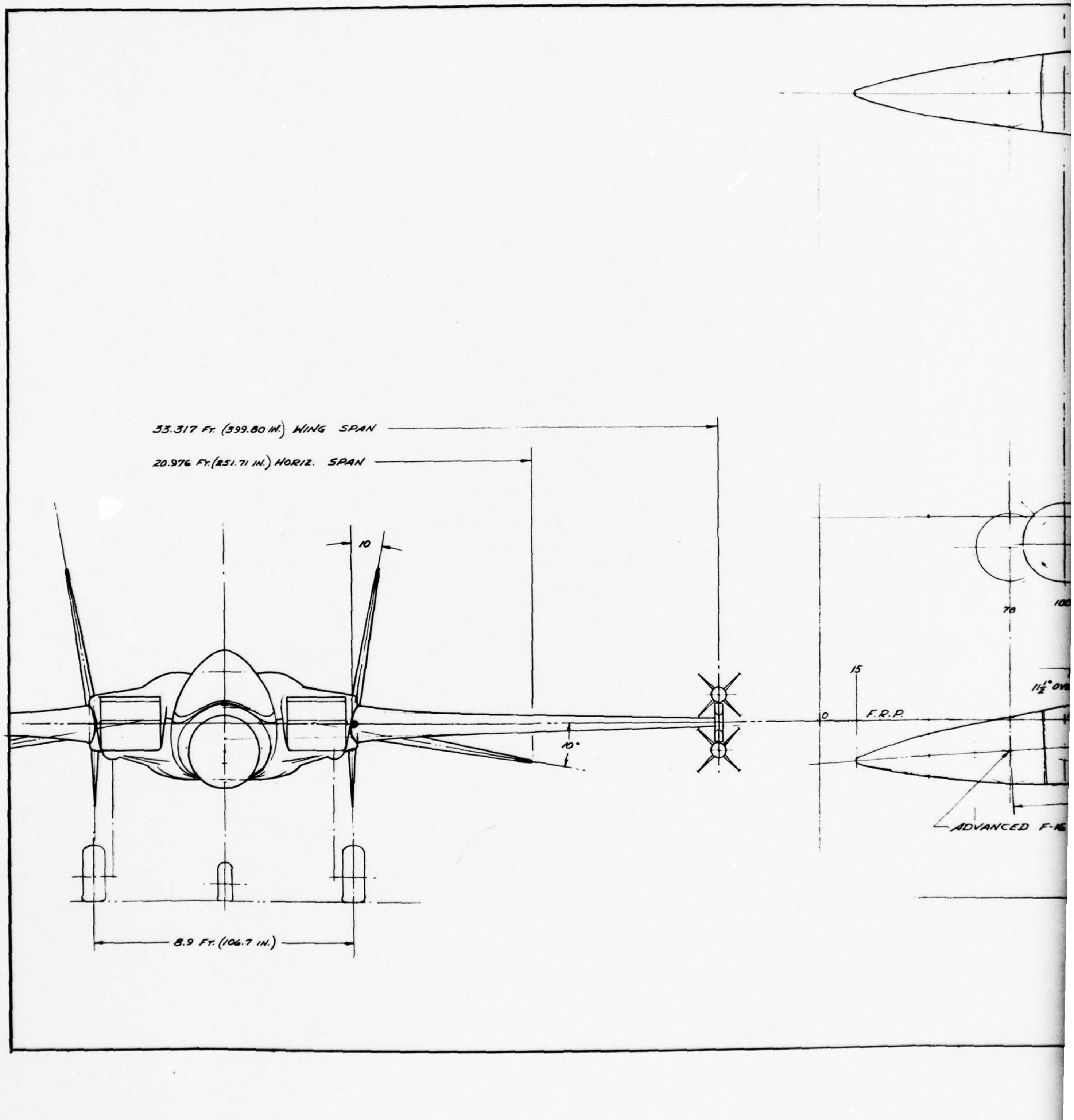
PROPULSION: FOUR (4) 150% SIZE GE F101 DRY ENGINES.
82,000 LB LIQUID HYDROGEN FUEL STORED AT 1 ATMOS PRESS @ -423°F.
TANK (FUSELAGE WALL CONSTRUCTED OF 3 LAYERS OF SPF/DB TITANIUM, 2" THICK WITH 2" THICK INSULATION.

TARGET WEIGHTS: T.O.G.W. = 365,000 LBS
FUEL WT = 82,000 LBS
PAYLOAD WT = 59,000 LBS (16 ALCM "B" MISSILES)

D661-30

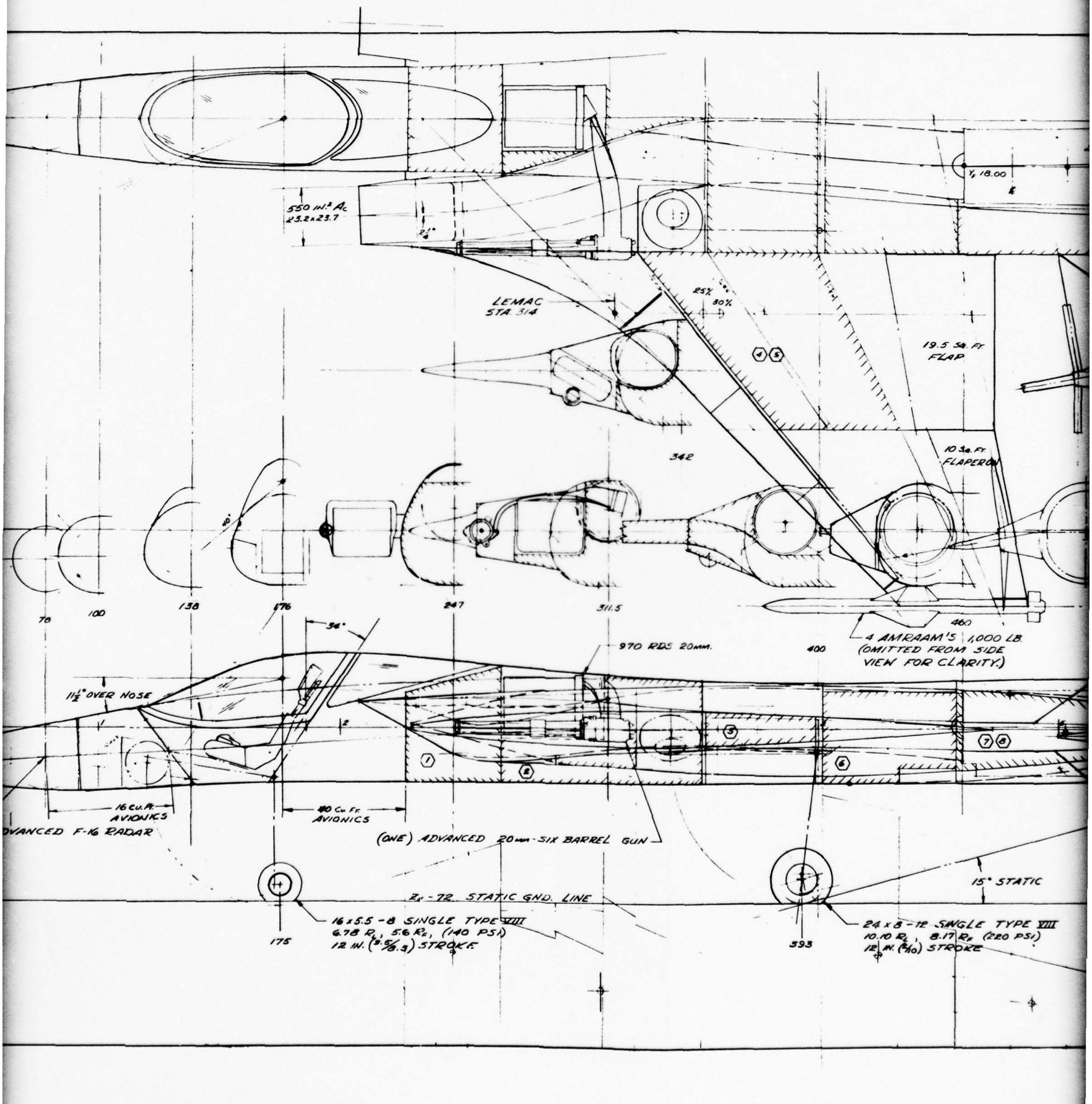
| SCALE 1/40 | DR McEACHAN DATE 6-12-78 | Rockwell International Corporation Los Angeles Aircraft Division | ADVANCED DESIGN |
|---|---|---|---|
| INBOARD PROFILE – LIQUID HYDROGEN POWERED STRIKE VEHICLE | | | D661-26 |

Figure 23. Inboard profile - liquid hydrogen powered strike vehicle.



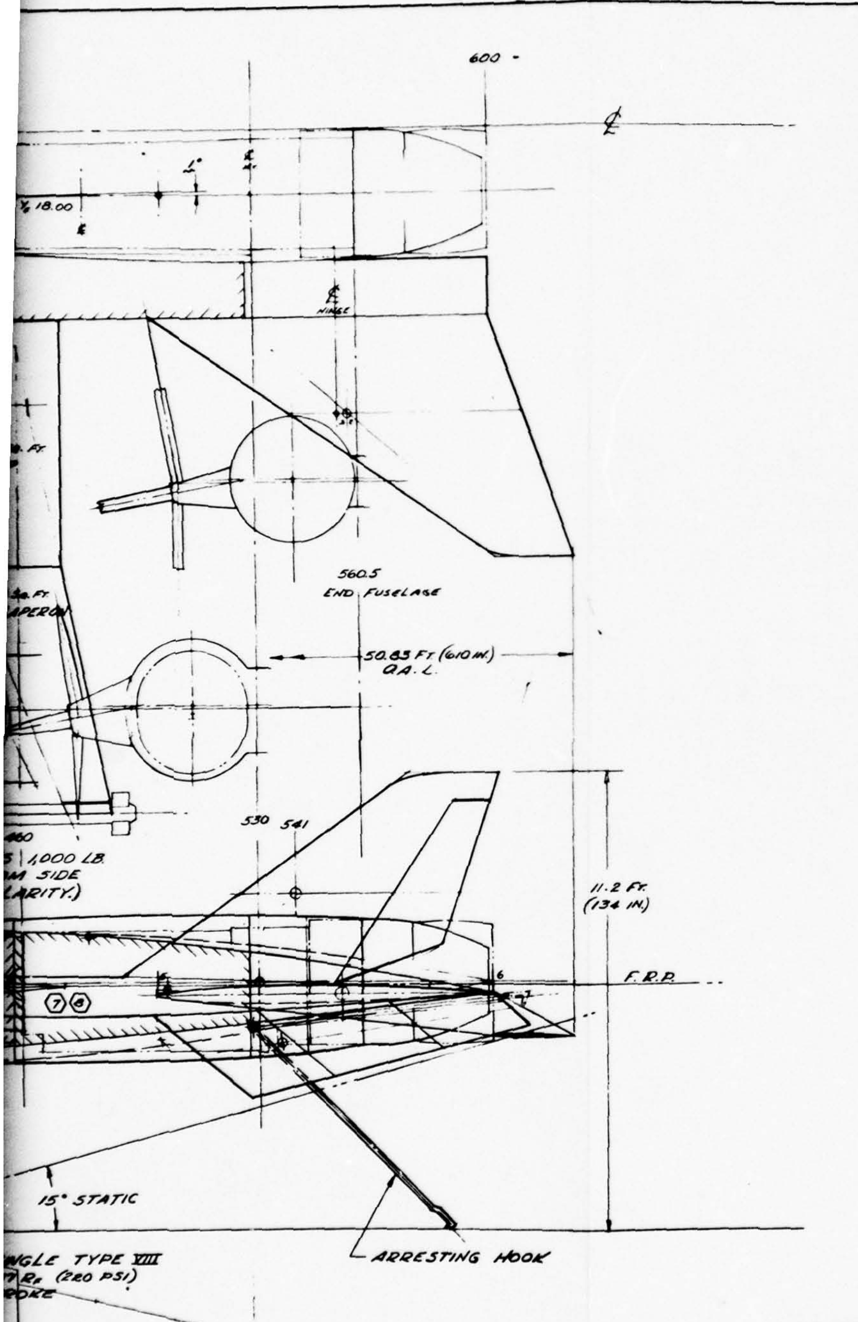
33.317 FT. (399.80 IN.) WING SPAN
20.976 FT. (251.71 IN.) HORIZ. SPAN
10
10°
15
0
F.R.P.
70
ADVANCED F-16
8.9 FT. (106.7 IN.)

2



550 IN.² $A_c$
23.2 x 23.7
$Y_F$ 18.00
LEMAC
STA. 314
25%
30%
19.5 SQ. FT.
FLAP
342
10 SQ. FT.
FLAPERON
78
100
138
176
247
311.5
460
4 AMRAAM'S 1,000 LB.
(OMITTED FROM SIDE
VIEW FOR CLARITY.)
400
34°
970 RDS 20MM.
$1\frac{1}{2}$° OVER NOSE
16 CU.FT.
AVIONICS
40 CU. FT.
AVIONICS
ADVANCED F-16 RADAR
(ONE) ADVANCED 20mm - SIX BARREL GUN
15° STATIC
$Z_F$ - 72 STATIC GND. LINE
16 x 5.5 - 8 SINGLE TYPE VIII
6.78 $R_L$, 5.6 $R_F$, (140 PSI)
12 IN. (3.5/8.5) STROKE
175
393
24 x 8 - 12 SINGLE TYPE VIII
10.10 $R_L$, 8.17 $R_F$ (220 PSI)
12 IN. (2/10) STROKE

3




GEOMETRIC DATA

| ITEM | WING TRAPEZOID | HORIZ. (TOTAL) | HORIZ. (EXP.) | VERT. EXP. EA. | VENTRAL EXP. EA. |
|---|---|---|---|---|---|
| S SQ. FT. | 370 | 160 | 61 | 25 | 13.3 |
| Æ | 3.00 | 2.75 | 2.289 | 1.00 | 0.38 |
| λ | 0.25 | 0.15 | 0.239 | 0.30 | 0.84 |
| $\Lambda_{LE}$ | 45° | 55° | 55° | 55° | 50° |
| t/c | 65A006 | ~ | 65A005.5 $C_R$ 65A003.5 $C_T$ | 65A005.5 $C_R$ 65A003.5 $C_T$ | [illegible] |
| b FT. | 33.317 | 20.976 | 11.82 | 5.00 | 2.25 |
| b/2 IN. | 199.90 | 125.857 | 70.9 | ~ | ~ |
| $C_R$ IN. | 213.227 | 159.187 | 100.06 | 92.308 | 100 |
| $C_T$ IN. | 53.307 | 23.878 | 23.878 | 27.692 | 84 |
| $\bar{c}$ IN. | 149.259 | 108.201 | 69.7 | 65.799 | 94 |
| $\bar{Y}$ IN. | 79.960 | 47.424 | 28.2 | 24.615 | 9.0 |
| Γ | 0° | -10° | -10° | 80° | 90° |
| ℓ IN. | ~ | ~ | 206.0 | 183 | 179 |
| V | ~ | ~ | .228 | .031 | .016 |

PROPULSION:

TWO 65% SIZE F 100-PW-100 ENGINES WITH C-D NOZZLES. HORIZONTAL RAMP EXTERNAL COMPRESSION INLETS $A_c$ = 550 IN.² EA. THRUST 15,600 LB, WT. 1900 LB.

INTERNAL FUEL:

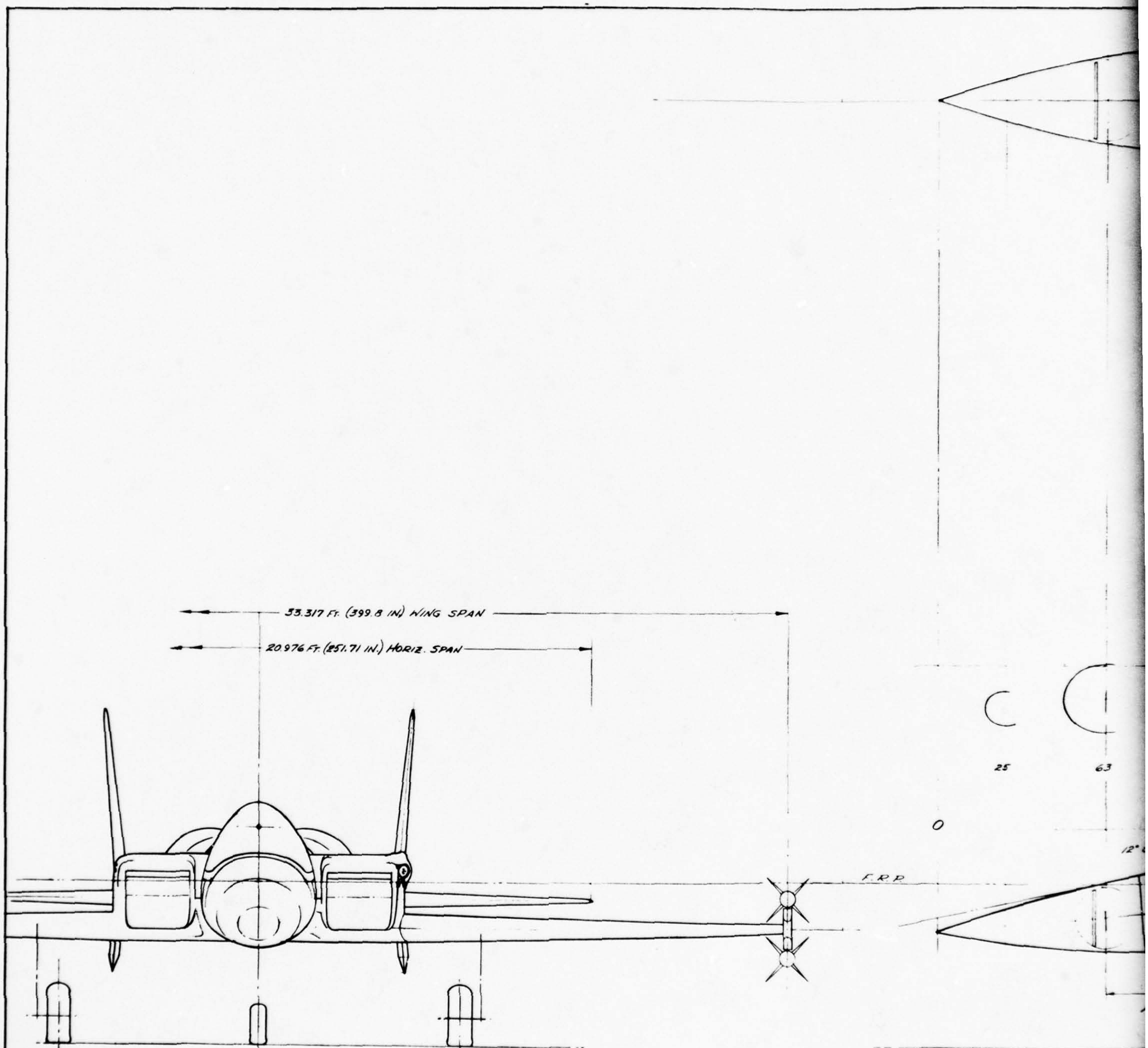
| TANK | CAPACITY | C.G. | MOMENT |
|---|---|---|---|
| #1 FUS. | 991 LB. | 247 | 244,777 |
| #2 FUS. | 1,324 " | 309 | 409,116 |
| #3 W.C.S. | 938 " | 374.5 | 351,281 |
| #4 WING | 594 " | 377 | 223,938 |
| #5 WING | 594 " | 377 | 223,938 |
| #6 FUS. | 1,434 " | 425.5 | 610,167 |
| #7 CHEEK | 408 " | 489.7 | 199,798 |
| #8 CHEEK | 408 " | 489.7 | 199,798 |
| TOTAL | 6,691 LB. | 368.0 | 2,462,812 |

TARGET WEIGHTS:

TOGW 26,000 LB.
AVIONICS 1,450 LB.
WFUEL 6,500 LB. PENTABORANE - 169 CU. FT.
6,000 LB. DIBORANE - 213 CU. FT.

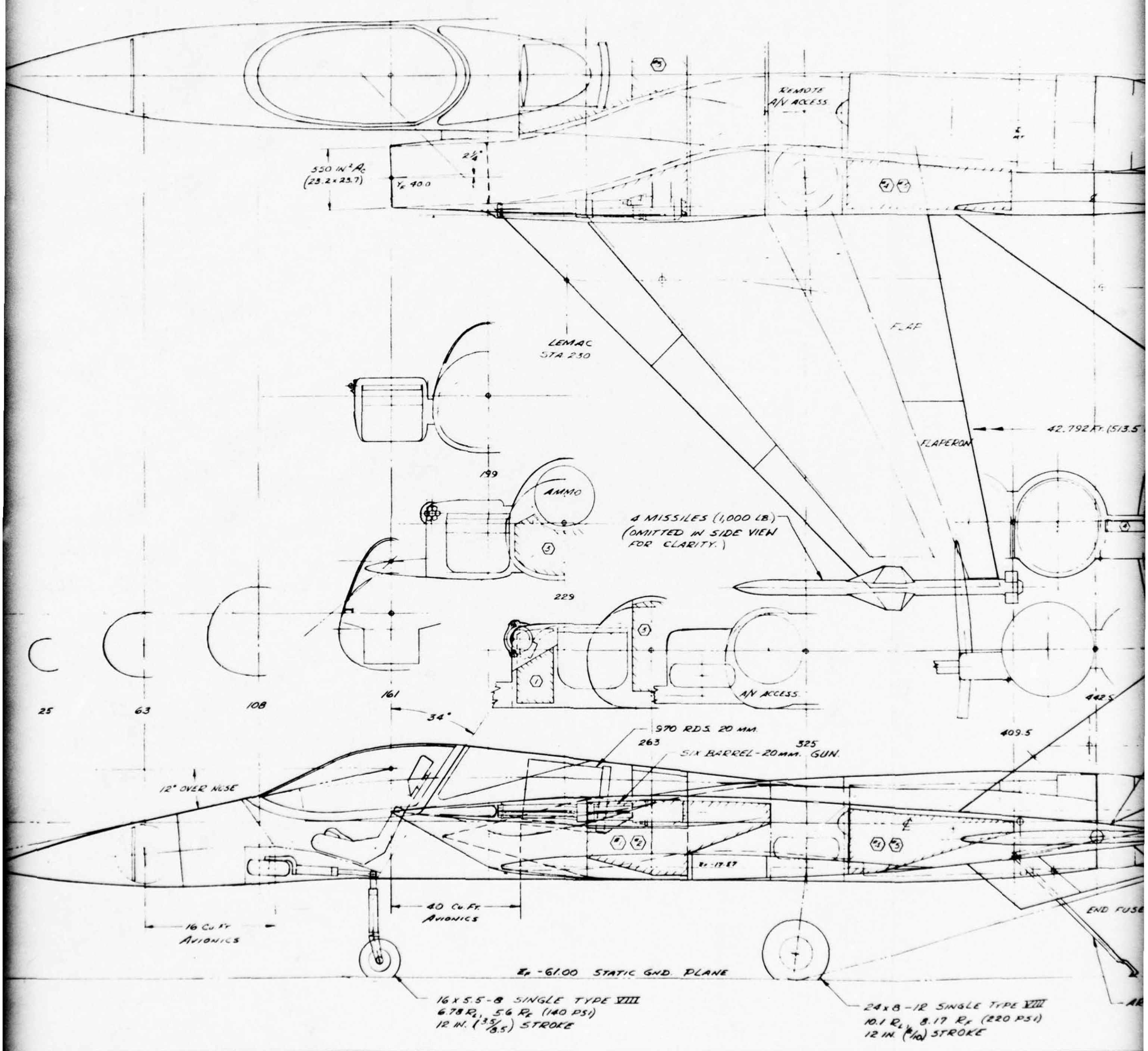
| SCALE: 1/20 | DR. B.L. ROGERS / DATE 5-26-76 / MODEL | Rockwell International Corporation, Los Angeles Aircraft Division, International Airport, Los Angeles, California | ADVANCED DESIGN |
|---|---|---|---|
| INBOARD PROFILE - PENTABORANE OR DIBORANE FUELED FIGHTER | | | D661-28 |

Figure 24. Inboard profile - pentaborane or diborane-fueled fighter.



33.317 FT. (399.8 IN.) WING SPAN
20.976 FT. (251.71 IN.) HORIZ. SPAN
F.R.P.
25
63
0

2

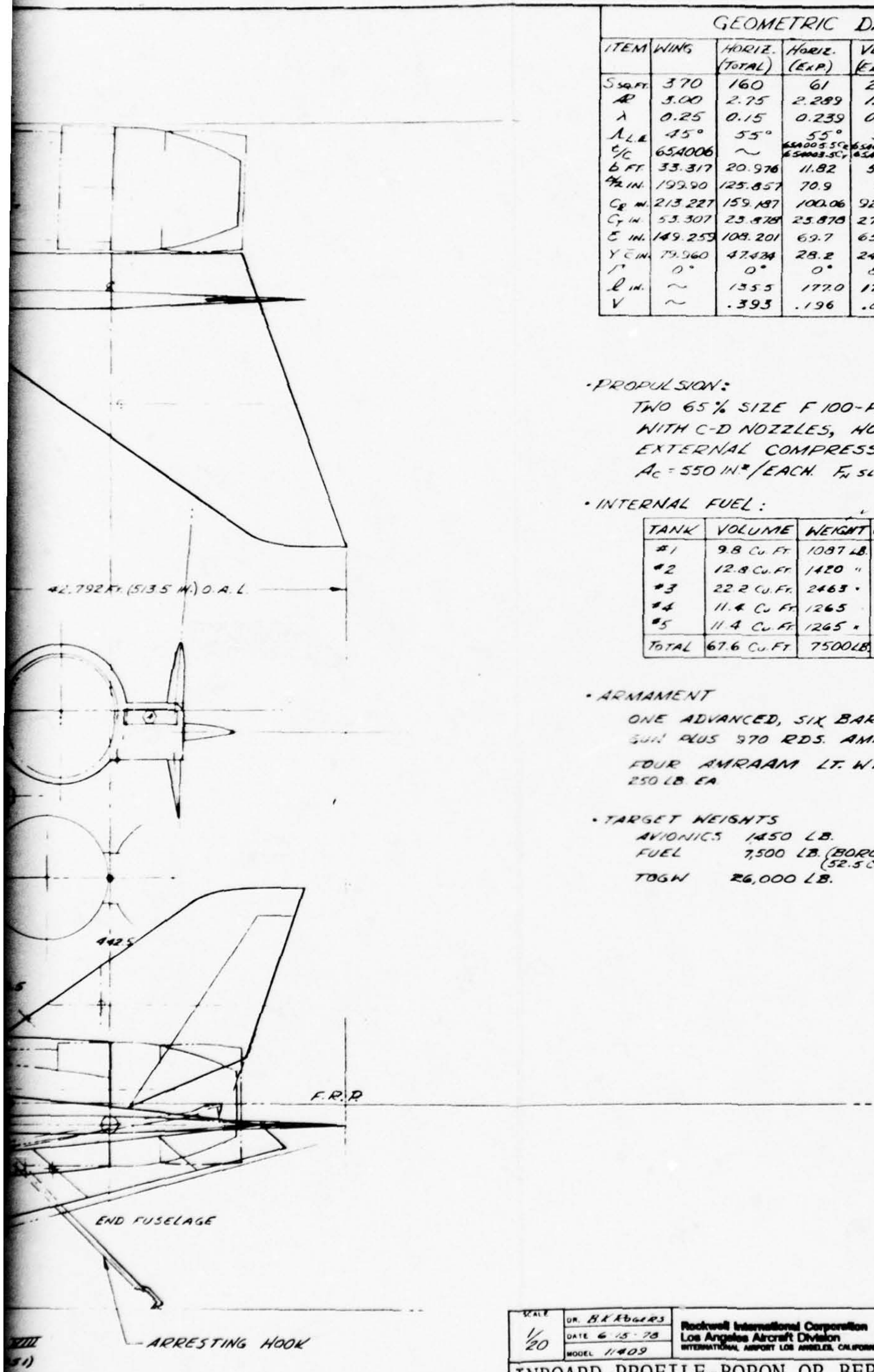


REMOTE A/V ACCESS
550 IN² $A_c$ (23.2 x 23.7)
$2\frac{1}{4}$"
$Y_F$ 40.0
FLAP
LEMAC STA 230
42.792 FT² (513.5
FLAPERON
199
AMMO
4 MISSILES (1,000 LB) (OMITTED IN SIDE VIEW FOR CLARITY.)
229
25
63
108
161
A/V ACCESS
442.5
34°
970 RDS. 20 MM.
263
325
SIX BARREL-20MM. GUN.
409.5
12" OVER NOSE
16 CU FT AVIONICS
40 CU FT AVIONICS
END FUSE
$Z_F$ -61.00 STATIC GND. PLANE
16 x 5.5-8 SINGLE TYPE VIII
6.78 $R_L$, 5.6 $R_F$ (140 PSI)
12 IN. (3.5/8.5) STROKE
24 x 8-12 SINGLE TYPE VIII
10.1 $R_L$, 8.17 $R_F$ (220 PSI)
12 IN. (4/10) STROKE


Figu

2

3




GEOMETRIC DATA

| ITEM | WING | HORIZ. (TOTAL) | HORIZ. (EXP.) | VERT. (EXP) EA. | VENTRAL (EXP) EA. |
|---|---|---|---|---|---|
| S SQ.FT. | 370 | 160 | 61 | 25 | 9.3 |
| AR | 3.00 | 2.75 | 2.289 | 1.00 | 0.30 |
| $\lambda$ | 0.25 | 0.15 | 0.239 | 0.30 | 1.00 |
| $\Lambda_{L.E.}$ | 45° | 55° | 55° | 55° | 50° |
| t/c | 65A006 | ~ | 65A005.5 $C_R$ 65A003.5 $C_T$ | 65A005.5 $C_R$ 65A003.5 $C_T$ | .040 × 30-70 HEX |
| b FT. | 33.317 | 20.976 | 11.82 | 5.00 | 1.666 |
| b/2 IN. | 199.90 | 125.857 | 70.9 | ~ | ~ |
| $C_R$ IN. | 213.227 | 159.187 | 100.06 | 92.308 | 110 |
| $C_T$ IN. | 53.307 | 23.878 | 23.878 | 27.692 | 110 |
| $\bar{C}$ IN. | 149.253 | 108.201 | 69.7 | 65.799 | 94 |
| Y $\bar{C}$ IN. | 79.960 | 47.434 | 28.2 | 24.615 | 9.0 |
| $\Gamma$ | 0° | 0° | 0° | 85° | -85° |
| $\ell$ IN. | ~ | 135.5 | 177.0 | 171.5 | 156.5 |
| V | ~ | .393 | .196 | .029 | .010 |

- PROPULSION:

  TWO 65% SIZE F100-PW-100 ENGINES WITH C-D NOZZLES, HORIZONTAL RAMP EXTERNAL COMPRESSION INLETS

  $A_C$ = 550 IN²/EACH. $F_N$ SLS 15,600 LB.- WT. = 1300 LB.

- INTERNAL FUEL:

| TANK | VOLUME | WEIGHT | C.G. | MOMENT |
|---|---|---|---|---|
| #1 | 9.8 Cu. Ft. | 1087 LB. | 294 | 319,578 IN. LB. |
| #2 | 12.8 Cu. Ft. | 1420 " | 289 | 410,380 " " |
| #3 | 22.2 Cu. Ft. | 2463 " | 241 | 593,583 " " |
| #4 | 11.4 Cu. Ft. | 1265 | 366 | 462,990 " " |
| #5 | 11.4 Cu. Ft. | 1265 " | 366 | 462,990 " " |
| TOTAL | 67.6 Cu. Ft. | 7500 LB. | 300 | 2,249,521 IN. LB. |

- ARMAMENT

  ONE ADVANCED, SIX BARREL, 20 MM. GUN PLUS 970 RDS. AMMO.

  FOUR AMRAAM LT. WT. MISSILES 250 LB. EA.

- TARGET WEIGHTS

  AVIONICS 1450 LB.

  FUEL 7,500 LB. (BORON OR BERYLLIUM) (52.5 Cu. Ft. 65 Cu. Ft.)

  TOGW 26,000 LB.

| SCALE 1/20 | DR. B.K. Rogers; DATE 6-15-78; MODEL 11409 | Rockwell International Corporation, Los Angeles Aircraft Division, International Airport Los Angeles, California 90009 | ADVANCED DESIGN |
|---|---|---|---|
| INBOARD PROFILE-BORON OR BERYLLIUM FUELED FIGHTER | | | D661-30 |

Figure 25. Inboard profile - boron or beryllium-fueled fighter.

Figure 26 shows the first alternate fuel area interceptor vehicle. This vehicle uses the same boron or beryllium fuel as does the air superiority fighter of Figure 25 but represents a different design philosophy for the fuel systems. In this vehicle, a constant cross-section fuel tank is used to allow a "sabot" or plug to be fitted such that the fuel will be fed to one end of each tank section, and from that point to the engine(s). This vehicle is in essence, designed around the fuel and its characteristics. Again, all nonfuel-system-related vehicle elements are the same as those of the conventional fuel basepoint.

The liquid-fuel version of the area interceptor is shown in Figure 27. This vehicle shows the impact of changing a solid/powdered fuel vehicle to a liquid fuel while maintaining the original design concept. As in the air superiority vehicle, the liquid-fuel version represents an increase in vehicle length and wetted area. Because this concept was tailored to the solid fuel, however, the increase is larger, as both cross section and length are varied to provide the necessary volume increase.

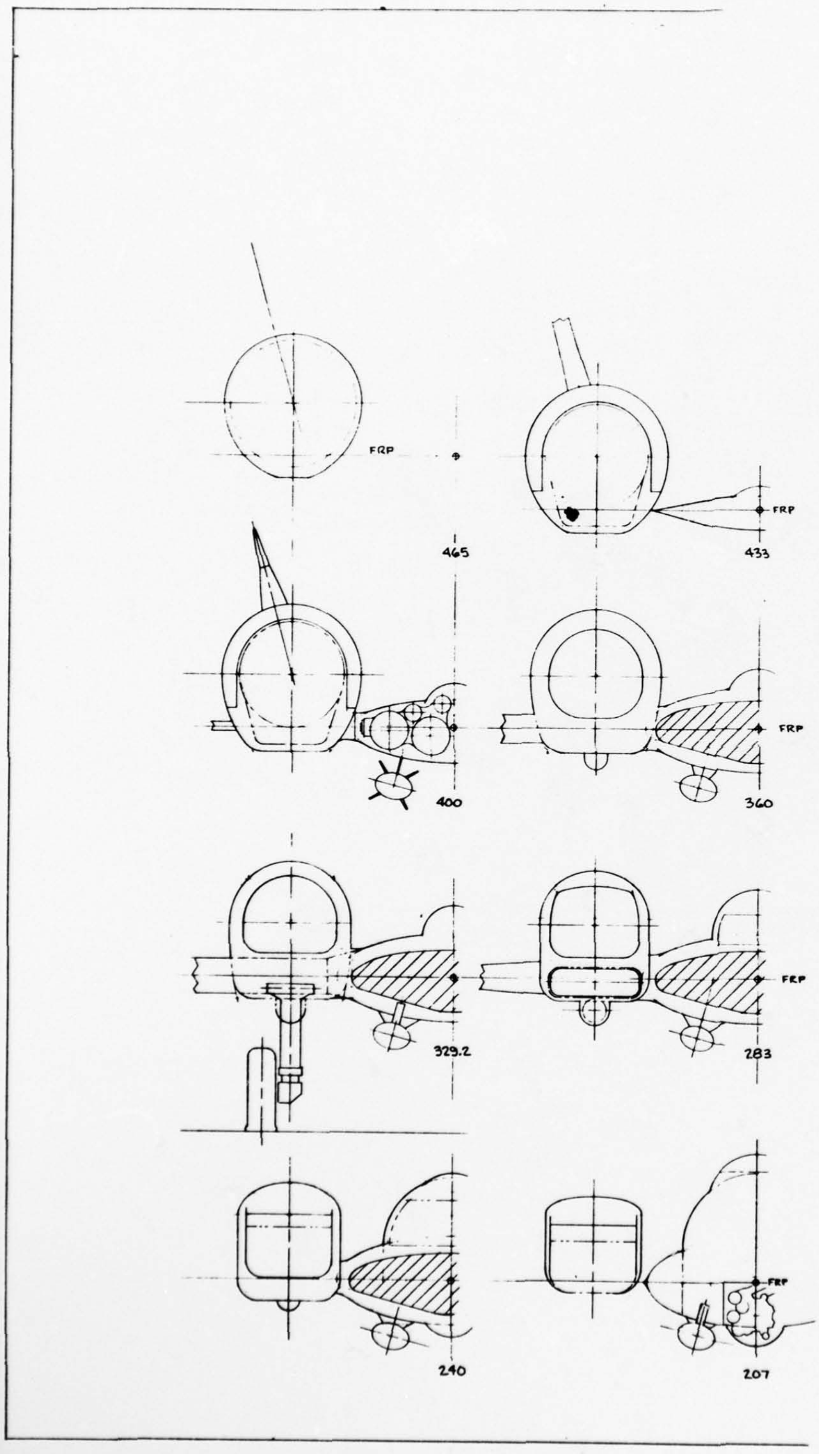
## MASS PROPERTIES

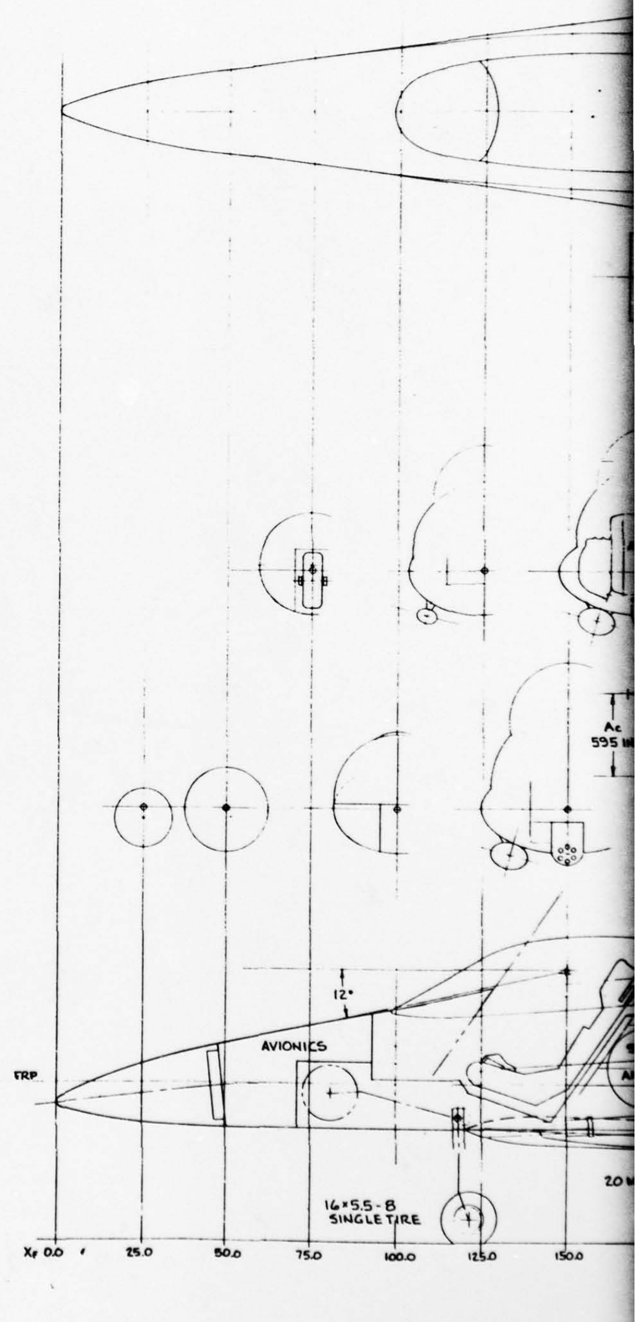
### Strike Vehicle.

Table 18 presents a comparison of the estimated weights for both of the strike vehicles. Although the target weights for the two vehicles were similar, the resulting estimated weights were divergent, and corrections for design weight effects, thrust loading, and wing loading will cause an increased difference. A short reoptimization of the nuclear vehicle could result in some improvement but is not expected to be substantial. Table 19 shows an estimated materials breakdown for both of these vehicles for the original estimated weights.

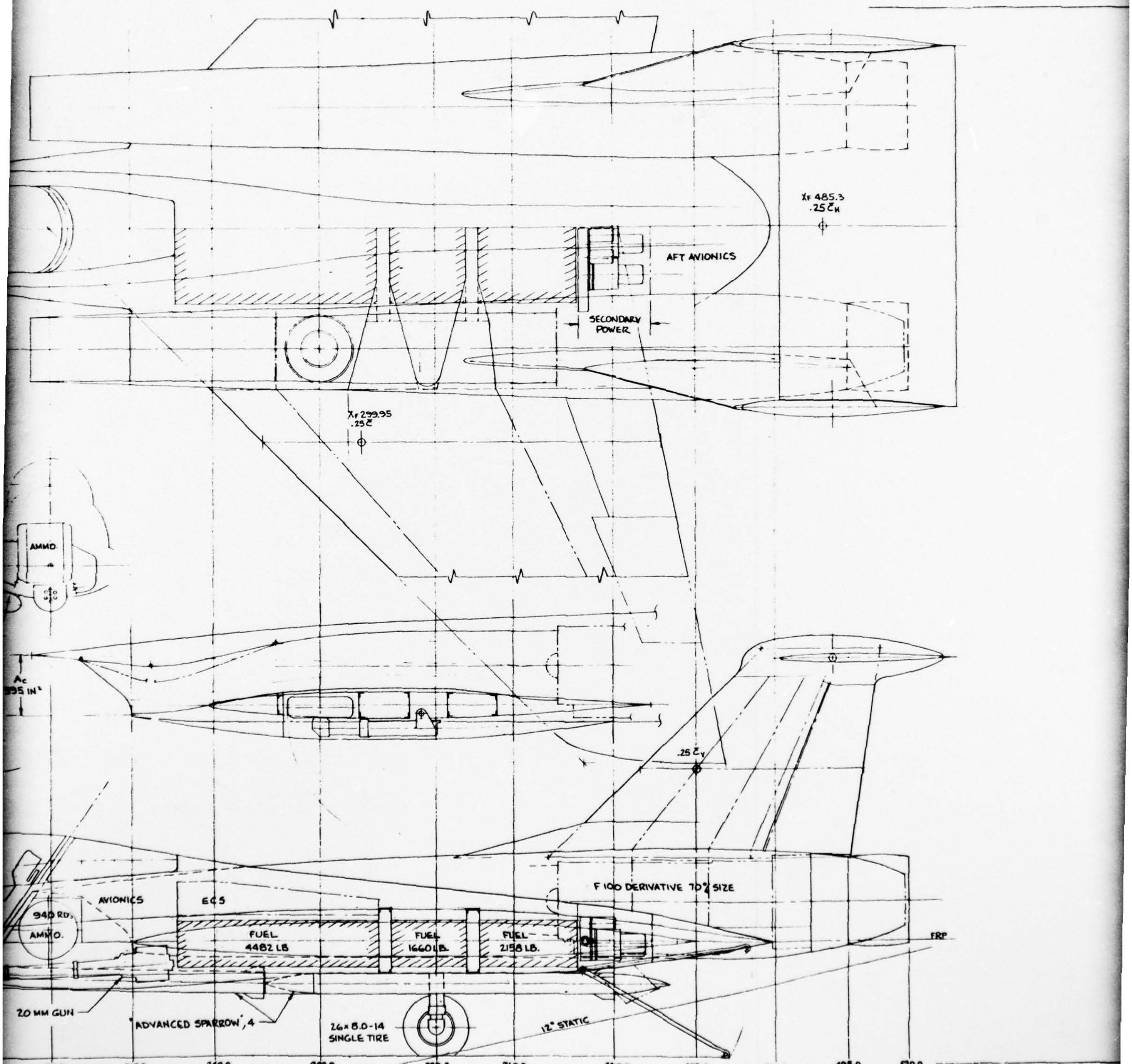
### Air Superiority

The pentaborane fuel version of air superiority fighter was estimated to be less than the target weight as was the boron fueled version. The breakdown of both vehicles is shown in Table 20. The difference in structural weight is due to the reduced size of the boron-fueled version; however, the increased weight of the fuel results in a higher takeoff gross weight. Table 21 shows an estimated materials breakdown for both vehicles. The slightly higher percentage of graphite/epoxy on the boron-fueled version is due to a common lifting surface definition between the two vehicles and a lower AMPR weight, but the actual weight of the composite material can be seen to be nearly identical between the two. The remaining systems of the vehicles are based on the advanced F-15A definition and are nearly identical.


FRP
465
433
FRP
400
360
FRP
329.2
283
FRP
240
207
FRP


Ac
595 IN
12°
AVIONICS
FRP
16×5.5-8
SINGLE TIRE
20
$X_F$ 0.0
25.0
50.0
75.0
100.0
125.0
150.0

2



Xf 485.3
.25 $\bar{C}_H$
AFT AVIONICS
SECONDARY POWER
Xf 299.95
.25 $\bar{C}$
AMMO.
Ac
395 IN²
.25 $\bar{C}_V$
AVIONICS
ECS
F 100 DERIVATIVE 70% SIZE
940 RDS
AMMO.
FUEL 4482 LB
FUEL 1660 LB.
FUEL 2158 LB.
FRP
20 MM GUN
"ADVANCED SPARROW", 4
26 x 8.0-14 SINGLE TIRE
12° STATIC
175.0
207.0
240.0
283.0
329.2
360.0
400.0
433.0
465.0
495.0
520.0


Figure 26.

2

3

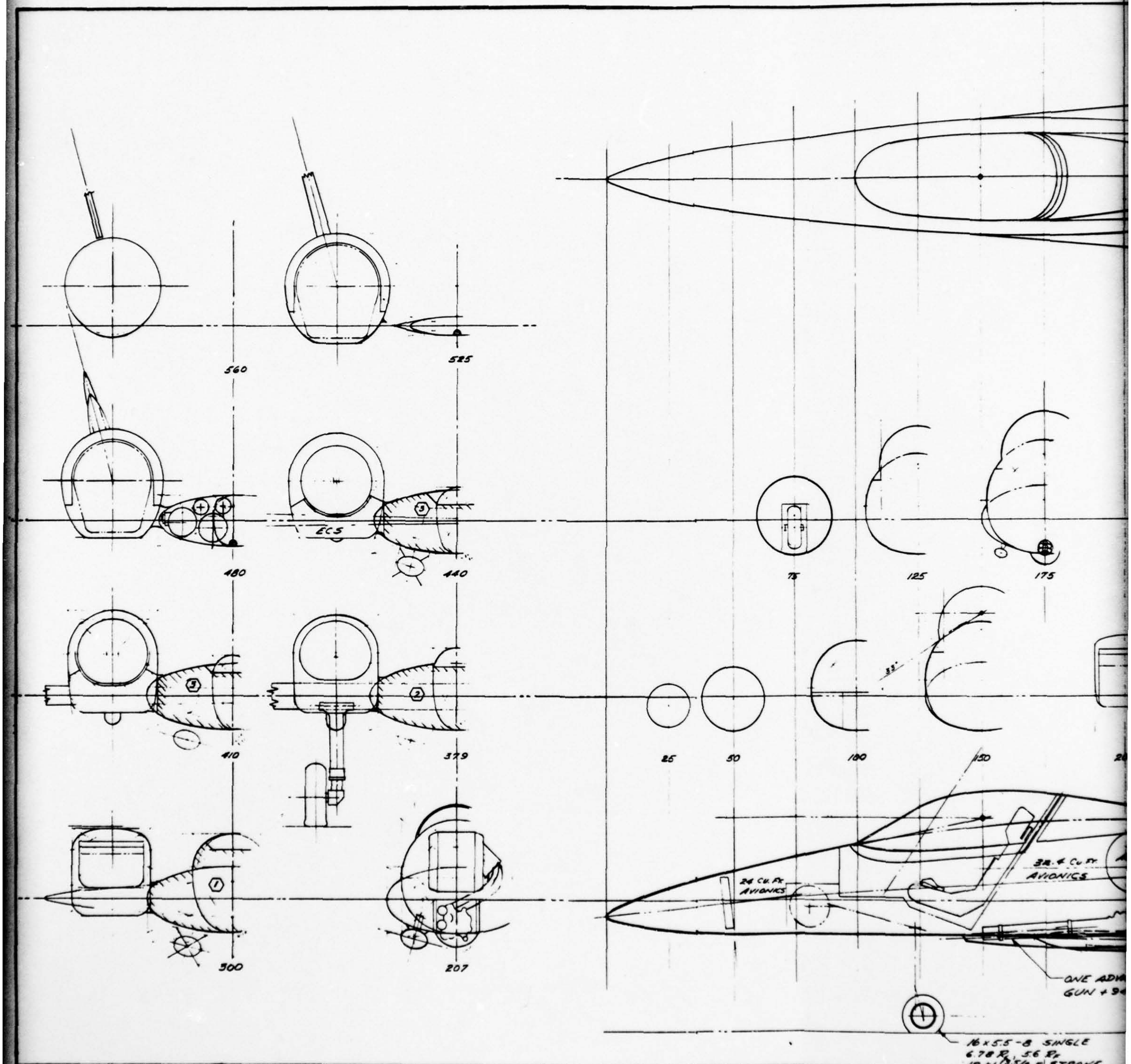
GEOMETRIC DATA

| ITEM | WING REF. GEOM. | HORIZ. | VERT. (EACH) |
|---|---|---|---|
| S FT² | 420 | 72.0 | 50.82 |
| AR | 3 | 2 | 1.0 |
| $\lambda$ | .25 | 1.0 | .40 |
| $\Lambda$ L.E. | 45° | 0° | 45° |
| AIRFOIL, ROOT | 65A006 | 65A005 | 65A005 |
| " , TIP | 65A006 | 65A005 | 65A005 |
| b IN. | 425.96 | 144 | 85.55 |
| $C_R$ IN. | 227.18 | 72 | 122.21 |
| $C_T$ IN. | 56.79 | 72 | 48.88 |
| $\bar{C}$ IN. | 159.02 | 72 | 90.78 |
| $\bar{Y}$ OR $\bar{Z}$ IN. | 85.19 | 0 | 36.66 |
| $\ell_T$ IN. | —— | 185.35 | 133.05 |
| $\bar{V}$ | —— | 0.1998 | .0756 |

2 JUNE STATUS: ADDED DEFINITION

| SCALE: 1/20 | DR. G. OWL<br>DATE 5-31-78<br>MODEL | Rockwell International Corporation<br>Los Angeles Aircraft Division | ADVANCED DESIGN |
|---|---|---|---|
| INBOARD PROFILE, BORON FUELED INTERCEPTOR | | | D661-29 |

Figure 26. Inboard profile - boron-fueled interceptor.



560
525
ECS
480
440
75
125
175
410
379
25
50
100
150
300
207
24 CU. FT.
AVIONICS
38.4 CU. FT.
AVIONICS
16 x 5.5-8 SINGLE

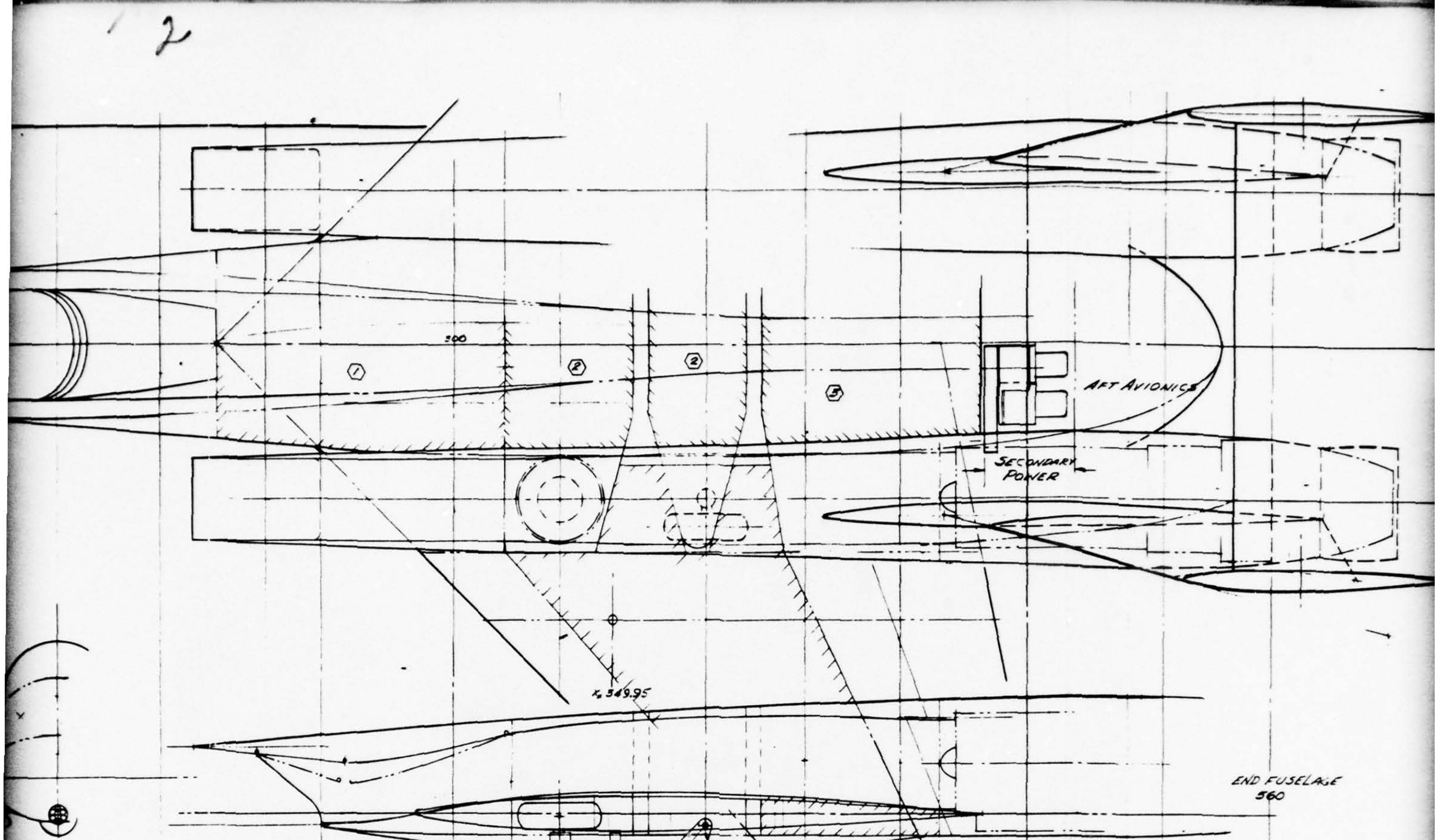
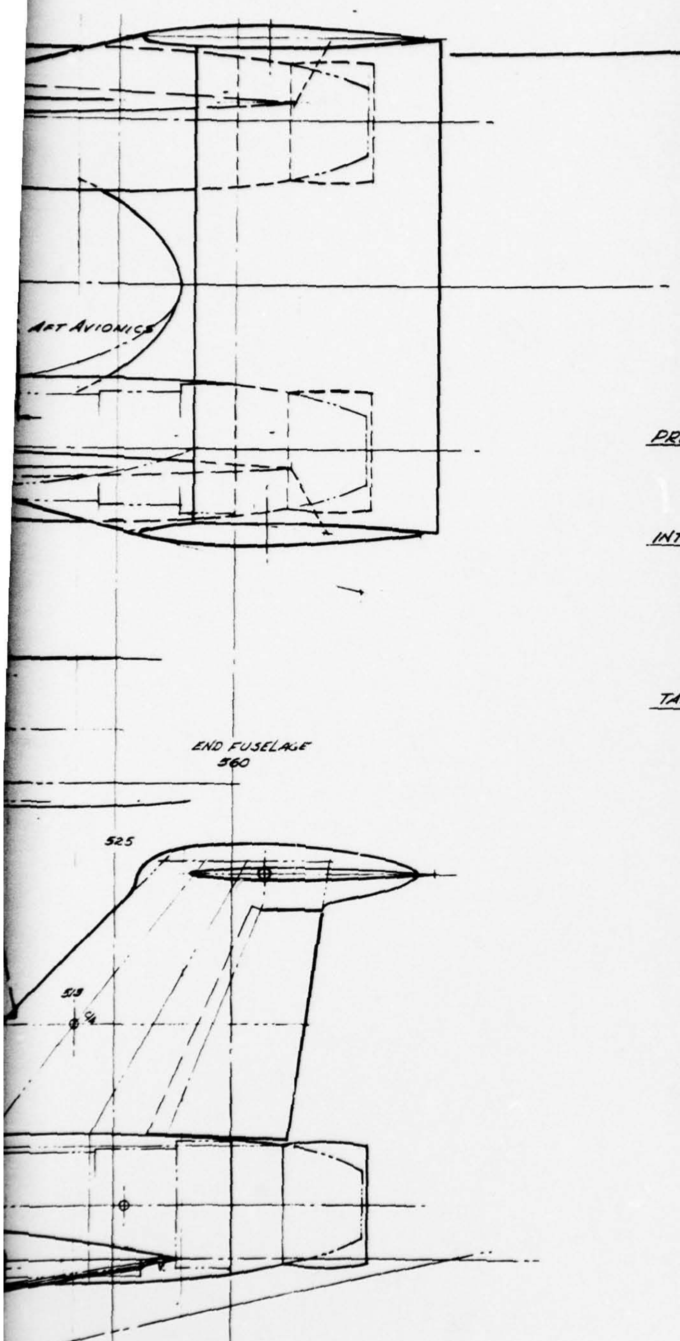



Figure 27. Inb




GEOMETRIC DATA
(SIMILAR TO D661-29)

| ITEM | WING | HORIZ. | VERT.(EA) |
|---|---|---|---|
| $S$ SQ. FT. | 420 | 72 | 50.82 |
| AR | 3.00 | 2.00 | 1.00 |
| $\lambda$ | 0.25 | 1.00 | 0.40 |
| $\Lambda_{L.E.}$ | 45° | 0° | 45° |
| $b$ FT. | 35.497 | 12.00 | 85.55 IN. |
| $b/2$ IN. | 212.98 | 72.00 | ~ |
| $C_R$ IN. | 227.18 | 72. | 122.21 |
| $C_T$ " | 56.79 | 72. | 48.88 |
| $\bar{C}$ " | 159.02 | 72. | 90.78 |
| $\bar{Y}$ or $\bar{Z}$ " | 85.19 | 0 | 36.66 |
| $\Gamma$ ° | 0° | 0° | 75° |
| $l_t$ IN. | ~ | 215.500 | 163.300 |
| $V$ | ~ | 0.232 | 0.0464 |
| AIRFOIL | 65A006 | 65A004 | 65A005 |

PROPULSION:

TWO 70% SIZE F100-PW-100 DERIVATIVE ENGINES WITH C-D NOZZLES, HORIZONTAL RAMP EXTERNAL COMPRESSION INLETS, $A_c$ = 595 IN.$^2$ /EACH.

INTERNAL FUEL CAPACITY:

| TANK NO. | VOLUME (GAL.) | C.G. | MOMENT | LBS. DIBORANE | LBS. PENTABORANE |
|---|---|---|---|---|---|
| #1 FUS. | 609 | 270 | 614,250 | 2275 | |
| #2 FUS. | 436 | 353 | 574,684 | 1628 | |
| #3 FUS. | 323 (512 AT.) | 432 | 520,992 | 1206 | |
| WING L.H. | 224 | 383 | 320,571 | 837 | |
| WING R.H. | 224 | 383 | 320,571 | 837 | |
| TOTAL | 1816 GAL. | 346.6 | 2,351,068 | 6783 | 9298 |

TARGET WEIGHTS:

$W_{FUEL}$ 6,650 LB. (238 CU. FT.) DIBORANE
7,200 LB. (188 CU. FT.) PENTABORANE

AVIONICS 1450 LB.

ARMAMENT 4 ADV. SPARROW + 20MM +940RDS

TOGW 29,000 LB.

| SCALE 1/20 | DR. B.K. ROGERS<br>DATE 6/27/78<br>MODEL 1M09 | Rockwell International Corporation<br>Los Angeles Aircraft Division<br>INTERNATIONAL AIRPORT LOS ANGELES, CALIFORNIA 90009 | ADVANCED DESIGN |
|---|---|---|---|
| INBOARD PROFILE - PENTABORANE /DIBORANE FUELED INTERCEPTOR | | | D661-31 |

Figure 27. Inboard profile - pentaborane or diborane-fueled interceptor.

TABLE 18. STRIKE VEHICLES ESTIMATED WEIGHT SUMMARY (INPUT)

| | Liquid Hydrogen | W/W (%)$^{o}$ | Nuclear | W/W (%)$^{o}$ |
|---|---|---|---|---|
| Structure groups | (128,430) | (41.1) | (86,740) | (21.6) |
| Wing | 40,000 | | 43,970 | |
| Tail - Horizontal | 4,260 | | 2,580 | |
| - Vertical | 1,370 | | - | |
| Body | 58,020 | | 15,340 | |
| Alighting gear - Main & auxiliary | 12,320 | | 12,820 | |
| Engine section or nacelle | 10,900 | | 6,610 | |
| Air induction System | | | 3,400 | |
| Wingtip fins | 1,100 | | 1,560 | |
| Arresting gear | 460 | | 460 | |
| Propulsion group | (15,540) | (5.0) | (208,140) | (51.7) |
| Engine (as installed) | 9,800 | | 12,400 | |
| Accessory gearboxes & drives | 600 | | 600 | |
| Exhaust system | 840 | | 960 | |
| Cooling & drain provisions | 80 | | 80 | |
| Engine controls | 100 | | 100 | |
| Starting system | 200 | | - | |
| Fuel system | 3,920 | | - | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Reactor/shield & installation | | | 194,000 | 48.2 |
| Equipment groups | (27,340) | (8.8) | (49,580) | (12.3) |
| Flight controls | 2,230 | | 2,130 | |
| Auxiliary powerplant | - | | | |
| Instruments | 760 | | 760 | |

TABLE 18. STRIKE VEHICLES ESTIMATED WEIGHT SUMMARY (INPUT) (CONCL)

| | Liquid Hydrogen | $W/W_o$ (%) | Nuclear | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Hydraulic & pneumatic | 1,410 | | 1,410 | |
| Electrical | 6,210 | | 6,210 | |
| Avionics | 9,980 | | 9,980 | |
| Armament | 4,090 | | 4,090 | |
| Furnishing and equipment | 1,480 | | 1,480 | |
| Air conditioning | 1,100 | | 1,100 | |
| Anti-icing | | | | |
| Photographic | 80 | | 80 | |
| Load & handling | | | | |
| Crew shield | | | 22,340 | |
| Total weight empty | 171,310 | 54.9 | 344,460 | 85.6 |
| Crew | 1,080 | | 1,080 | |
| Fuel - Unusable | 820 | | - | |
| Fuel - Usable | 82,000 | 26.3 | - | |
| Oil - Engine | 400 | | 400 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Missiles (24) | 50,000 | 16.0 | 50,000 | 12.4 |
| Flares | 270 | | 270 | |
| Missile launchers | 5,100 | | 5,100 | |
| Equipment | | | | |
| $O_2$ | 100 | | 100 | |
| Chaff | 1,020 | | 1,020 | |
| Total useful load | 140,790 | 45.1 | 57,970 | 14.4 |
| Takeoff gross weight | 312,100 | 100.0 | 402,430 | 100.0 |
| Flight design gross weight | | | | |
| Gross weight target | 365,000 | | 380,000 | |

TABLE 19. STRIKE VEHICLE MATERIALS MIX SUMMARY

| | Liquid hydrogen | Nuclear |
|---|---|---|
| Structure - Total | 128,430 lb | 86,740 lb |
| - AMPR | 125,100 lb | 83,280 lb |
| | (Percent of AMPR) | |
| Aluminum | 54.5 | 44.3 |
| Titanium | 8.1 | 6.2 |
| Steel | 8.2 | 9.4 |
| Graphite/epoxy | 20.3 | 32.8 |
| Al honeycomb | 1.9 | 1.8 |
| G/E honeycomb | 2.3 | 2.2 |
| Fiberglass | 2.0 | 1.3 |
| Other | 2.7 | 2.0 |
| Propulsion - Total | 15,540 | 208,140 |
| - AMPR | 5,600 | 198,340 |
| Equipment - Total | 27,340 | 49,580 |
| - AMPR | 17,680 | 39,920 |
| Weight empty | 171,310 | 344,460 |
| AMPR weight | 148,380 | 321,540 |

TABLE 20. AIR SUPERIORITY VEHICLES ESTIMATED WEIGHT SUMMARY (INPUT)

| | Penta-Borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Structure groups | (6,940) | (29.3) | (6,220) | (25.5) |
| Wing | 1,595 | | 1,585 | |
| Tail - Horizontal | 285 | | 280 | |
| - Vertical | 230 | | 205 | |
| Body | 3,210 | | 2,590 | |
| Alighting gear - Main | 600 | | 600 | |
| - Auxiliary | 150 | | 150 | |
| Engine section or nacelle | 40 | | 40 | |
| Air induction system | 765 | | 705 | |
| Arresting gear | 65 | | 65 | |
| Propulsion group | (3,280) | (13.9) | (3,300) | (13.6) |
| Engine (as installed) | 2,600 | | 2,600 | |
| Accessory gearboxes & drives | | | | |
| Exhaust system | | | | |
| Cooling & drain provisions | | | | |
| Engine controls | 30 | | 30 | |
| Starting system | | | | |
| Fuel system | 650 | | 670 | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Equipment groups | (4,945) | (20.9) | (5,000) | (20.5) |
| Flight controls | 765 | | 815 | |
| Auxiliary powerplant | 315 | | 315 | |
| Instruments | 120 | | 120 | |
| Hydraulic & pneumatic | 330 | | 350 | |
| Electrical | 520 | | 520 | |

TABLE 20. AIR SUPERIORITY VEHICLES ESTIMATED WEIGHT SUMMARY (INPUT) (CONCL)

| | Penta-borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Avionics | 1,450 | | 1,450 | |
| Armament | 550 | | 550 | |
| Furnishings and equipment | 240 | | 240 | |
| Air conditioning | 655 | | 640 | |
| Anti-icing | | | | |
| Photographic | | | | |
| Load & handling | | | | |
| Total weight empty | 15,165 | 64.1 | 14,520 | 59.6 |
| Crew | 215 | | 215 | |
| Fuel - Unusable | 65 | | 375 | |
| Fuel - Usable | 6,500 | 27.5 | 7,500 | 30.8 |
| Oil - Engine | 80 | | 80 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Gun - 20 MM | 200 | | 200 | |
| Ammo - 940 rd/Al cases | 375 | | 375 | |
| Missiles - (4) air-to-air | 800 | 3.4 | 800 | 3.3 |
| Missile launchers - Wingtip | 200 | | 200 | |
| Equipment | | | | |
| Chute & survival kit | 60 | | 60 | |
| LOX & converter | 20 | | 20 | |
| Total useful load | 8,515 | 35.9 | 9,825 | 40.4 |
| Takeoff gross weight | 23,680 | 100.0 | 24,345 | 100.0 |
| Flight design gross weight | | | | |
| Gross weight target | 26,000 | | 26,000 | |

TABLE 21. AIR SUPERIORITY VEHICLE MATERIALS MIX SUMMARY

| | Pentaborane | Boron |
|---|---|---|
| Structure - Total | 6,940 lb | 6,220 lb |
| - AMPR | 6,675 lb | 5,955 lb |
| | (Percent of AMPR) | |
| Aluminum | 30.6 | 29.1 |
| Titanium | 38.7 | 37.6 |
| Steel | 6.2 | 7.0 |
| Graphite/epoxy | 17.6 | 19.3 |
| Fiberglass | 1.4 | 1.5 |
| Other | 5.5 | 5.5 |
| Propulsion - Total | 3,280 | 3,300 |
| - AMPR | 490 | 620 |
| Equipment - Total | 4,945 | 5,000 |
| - AMPR | 3,155 | 3,210 |
| Weight empty | 15,165 | 14,520 |
| AMPR weight | 10,320 | 9,785 |

### Interceptor

The pentaborane-fueled version of the interceptor vehicle shows results similar to those of the air superiority vehicle. Both it and the boron-fueled version again resulted in a vehicle of less than target weight. The boron-fueled version weight breakdown and materials usage are summarized in Tables 22 and 23, respectively.

## PROPULSION

All systems were designed to be compatible with the basepoint (F-15A) vehicle constraints; therefore, the propulsion system performance is expected to be identical to that assumed for the advanced technology version of that vehicle. Fuel flow characteristics vary inversely with the ratio of the fuel heating value to that of the reference (JP-4).

## AERODYNAMICS

An analysis of the vehicles as drawn for each of the missions resulted in aerodynamic characteristics slightly different from those estimated from the parametric baselines, and the difference between target weights and estimated weights resulted in wing areas also different from the desired. The input data to the computer sizing program were used to supply a new data base upon which parametric variations could be accomplished. The resulting aerodynamic characteristics are presented for the resized vehicles, which complete the missions as defined and hold the wing loading and thrust loading of the conventional baseline vehicles.

### Strike Vehicle

The drag polars of both alternate fuel versions and the advanced technology baseline are shown in Figure 28. The polar presented is at 0.90 Mach at 50 feet to allow comparison to the current technology baseline polars presented earlier. These polars show the effects of reduced static stability, which allowed reductions in trim drag and wetted area. The delay in drag rise due to compressibility is contributory to the low values of zero lift/drag.

### Air Superiority Fighter

The 0.90-Mach drag polars for a 30,000-foot altitude are shown in Figure 29. Again, the advanced technology baseline is shown in comparison to the two vehicles whose size and wing loading have been corrected to the desired radius capability. The major change shown here is due to a large reduction in wetted area for the higher energy fuel vehicles, resulting in a lower zero lift drag

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THE IMPACT OF ALTERNATE FUELS ON AIRCRAFT CONFIGURATION CHARACT--ETC(U)
OCT 78  D A ROBINSON    F33615-77-C-3155
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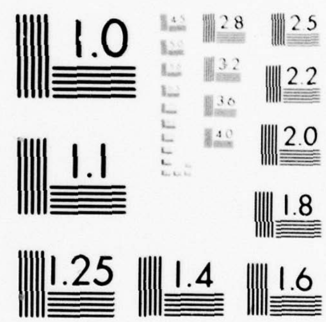


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 22. INTERCEPTOR VEHICLE ESTIMATED WEIGHT SUMMARY (INPUT)

| | Penta-borane | W/W (%)$^{o}$ | Boron | W/W (%)$^{o}$ |
|---|---|---|---|---|
| Structure groups | (8,620) | (31.4) | (8,115) | (29.0) |
| Wing | 1,835 | | 1,835 | |
| Tail - Horizontal | 335 | | 335 | |
| - Vertical | 305 | | 305 | |
| Body | 2,040 | | 1,760 | |
| Alighting gear - Main | 665 | | 665 | |
| - Auxiliary | 165 | | 165 | |
| Engine section or nacelle | 2,355 | | 2,155 | |
| Air induction system | 850 | | 825 | |
| Arresting gear | 70 | | 70 | |
| Propulsion group | (3,575) | (13.0) | (3,560) | (12.7) |
| Engine (as installed) | 2,800 | | 2,800 | |
| Accessory gearboxes & drives | | | | |
| Exhaust system | | | | |
| Cooling & drain provisions | | | | |
| Engine controls | 30 | | 30 | |
| Starting system | | | | |
| Fuel system | 745 | | 730 | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Equipment groups | (5,040) | (18.3) | (5,015) | (17.9) |
| Flight controls | 740 | | 740 | |
| Auxiliary power plant | 330 | | 330 | |
| Instruments | 120 | | 120 | |
| Hydraulic & pneumatic | 330 | | 320 | |
| Electrical | 520 | | 520 | |

TABLE 22. INTERCEPTOR VEHICLE ESTIMATED WEIGHT SUMMARY (INPUT) (CONCL)

| | Penta-borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Avionics | 1,450 | | 1,450 | |
| Armament | 655 | | 655 | |
| Furnishings and equipment | 240 | | 240 | |
| Air conditioning | 655 | | 640 | |
| Anti-icing | | | | |
| Photographic | | | | |
| Load & handling | | | | |
| Total weight empty | 17,235 | 62.7 | 16,690 | 59.7 |
| Crew | 215 | | 215 | |
| Fuel - Unusable | | | | |
| Fuel - Usable | 7,270 | 26.2 | 8,300 | 29.7 |
| Oil - Engine | 100 | | 100 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Gun - 20 MM | 200 | | 200 | |
| Ammo - 940 rd/Al cases | 375 | | 375 | |
| Missiles - (4) air-to-air | 2,000 | 7.3 | 2,000 | 7.2 |
| Equipment | | | | |
| Chute & survival kit | 60 | | 60 | |
| LOX & converter | 20 | | 20 | |
| Total useful load | 10,240 | 37.3 | 11,270 | 40.3 |
| Takeoff gross weight | 27,475 | 100.0 | 27,960 | 100.0 |
| Flight design gross weight | | | | |
| Gross weight target | 29,000 | | 29,000 | |

TABLE 23. INTERCEPTOR MATERIALS MIX SUMMARY

| | Pentaborane | Boron |
|---|---|---|
| Structure - Total | 8,620 lb | 8,115 lb |
| - AMPR | 8,320 lb | 7,815 lb |
| | (Percent of AMPR) | |
| Aluminum | 38.5 | 37.1 |
| Titanium | 32.5 | 32.5 |
| Steel | 5.5 | 5.9 |
| Graphite/epoxy | 16.3 | 17.4 |
| Fiberglass | 1.3 | 1.3 |
| Other | 5.9 | 5.8 |
| Propulsion - Total | 3,575 lb | 3,560 lb |
| - AMPR | 530 lb | 670 lb |
| Equipment - Total | 5,040 lb | 5,015 lb |
| - AMPR | 3,250 lb | 3,225 lb |
| Weight empty | 17,235 lb | 16,690 lb |
| AMPR weight | 12,100 lb | 11,710 lb |

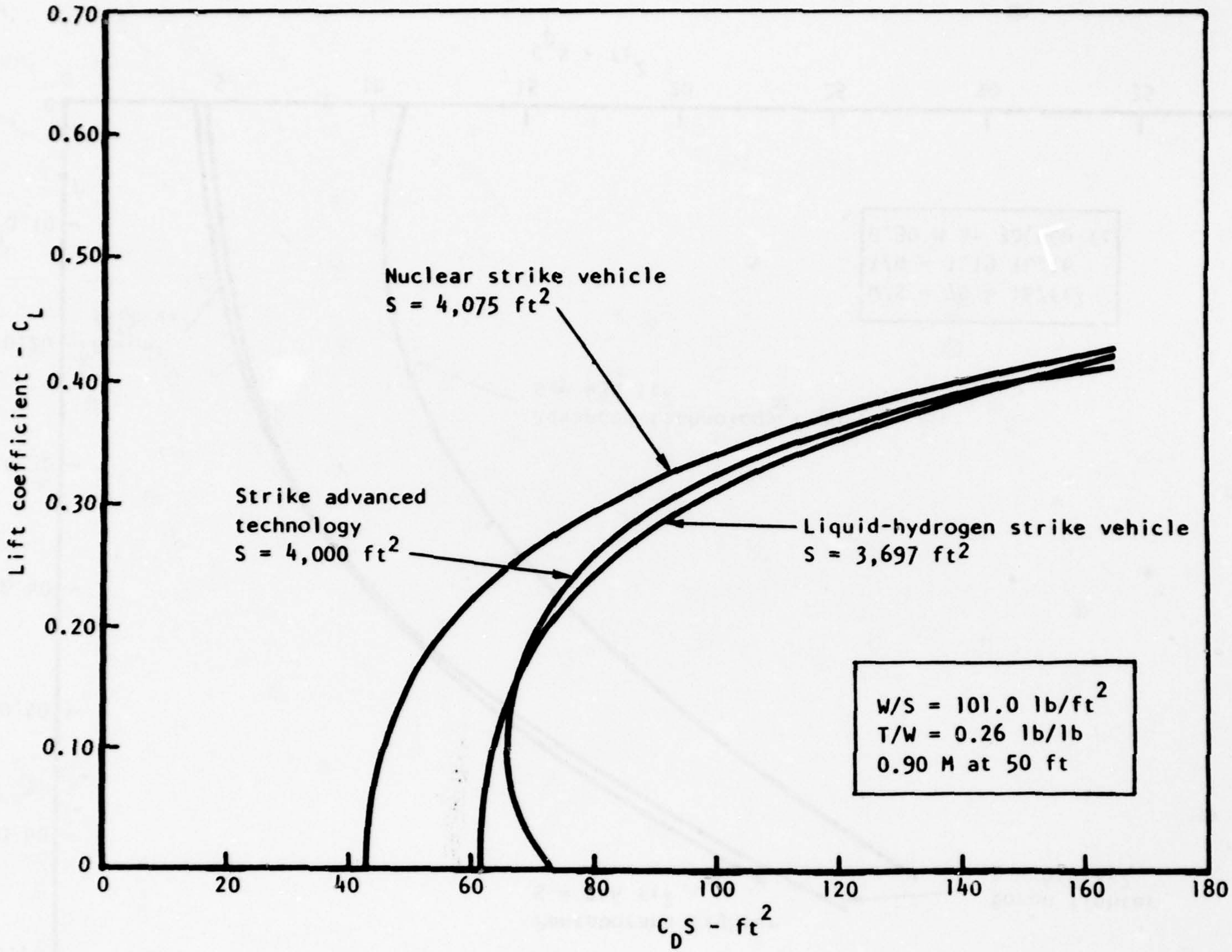


Figure 28. Strike vehicle penetration polars.

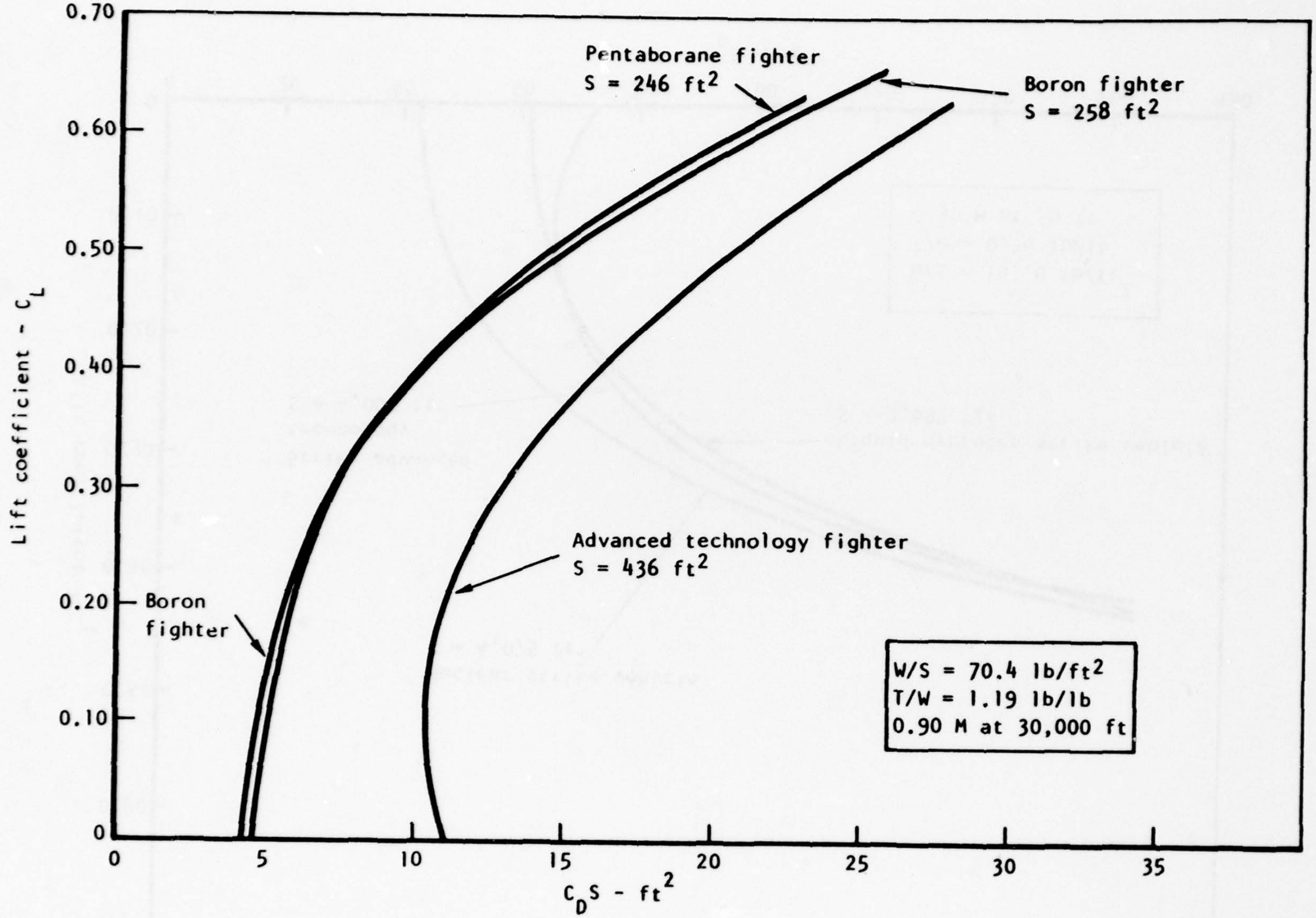


Figure 29. Air superiority maneuver polar.

than estimated. Drag-due-to-lift, however, was not as good as estimated, as evidenced by the convergence in polars at higher lift coefficients. The low value of zero lift drag as compared to the current technology vehicle is due to the high-acceleration cockpit design, which resulted in reduced wave drag at this speed.

### Area Interceptor

The aerodynamic characteristics of the area interceptor vehicles are shown in Figure 30. These characteristics are similar to those of the air superiority fighter vehicles.

## VEHICLE PERFORMANCE

The alternate fuel vehicles previously defined were used as revised data bases for a performance and sizing verification. In this process, these vehicles were parametrically varied to result in a vehicle whose size and fuel capacity were sufficient to perform the desired mission profile and whose thrust loading and wing loading were equal to a specified value for each mission. Results for each mission are discussed in the following paragraphs, and the resulting vehicles are presented.

### Strategic Strike Mission Vehicles

The two vehicles which were configured for this mission used nuclear and hydrogen fuels. Based on the JP- powered basepoint design, the thrust loading and wing loading were selected as 0.26 and 101 psf, respectively. Using the estimated weights presented earlier,the results of the aerodynamic technical evaluation, and the previously explained parametric sizing methodology, vehicles were selected capable of accomplishing the strike mission. A summary of the characteristics of the selected nuclear vehicle is shown in Table 24, while the selected liquid-hydrogen vehicle characteristics are included in Table 25. As can be seen, the strike vehicles are in the 400,000-pound class. A weight breakdown summary for both selected vehicles is included in Table 26.

The strategic strike mission has been found to be sensitive to changes in thrust loading. Although a 7,000-foot takeoff distance requirement originally determined the thrust loading, an increase in required liftoff velocity due to a decrease in attainable lift coefficient increased this value to over 8,500 feet. Reoptimization of the aircraft thrust-to-weight and wing loading ratios would result in improvement; however, it is felt that the takeoff

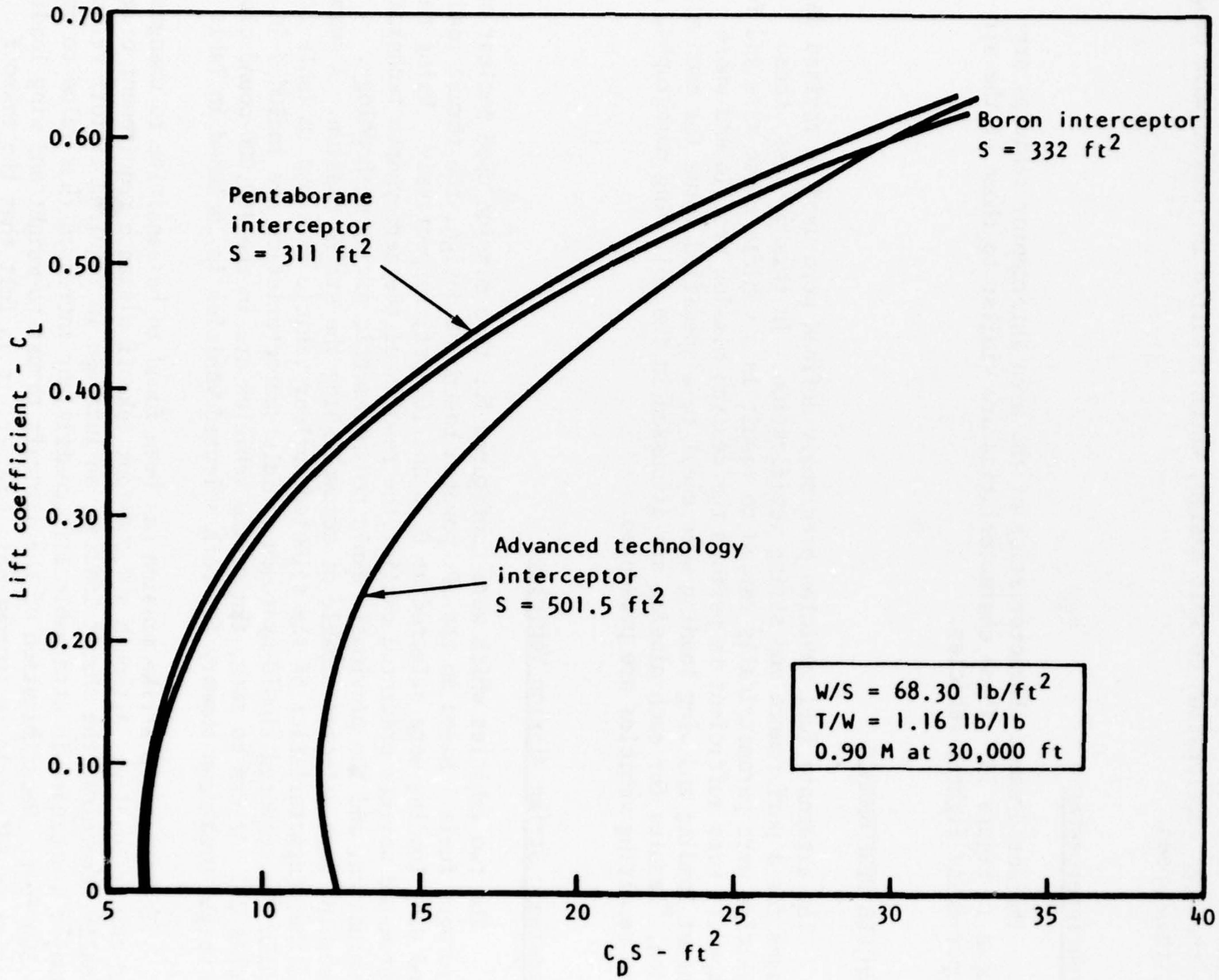


Figure 30. Area interceptor maneuver polar.

TABLE 24. SELECTED NUCLEAR STRIKE VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 411,569 lb |
| Wing area | 4,075 sq ft |
| Wing loading (takeoff) | 101.0 psf |
| Propulsion system - 4 adv technology modified dry F101 engines using nuclear fuel | |
| Thrust loading (takeoff) | 0.26 |
| Weight payload | 50,000 lb |
| Penetration Mach number | 0.85 |
| Takeoff distance | 8,595 ft |

TABLE 25. SELECTED LIQUID-HYDROGEN STRIKE VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 373,421 lb |
| Wing area | 3,697 sq ft |
| Wing loading | 101.0 psf |
| Propulsion system - 4 adv technology dry F101 engines using liquid-hydrogen fuel | |
| Thrust loading (takeoff) | 0.26 |
| Weight fuel | 113,386 lb |
| Weight payload | 50,000 lb |
| Penetration Mach number | 0.85 |
| Takeoff distance | 8,808 ft |

TABLE 26. STRIKE SELECTED VEHICLES WEIGHT SUMMARY

| | Liquid hydrogen | $W/W_o$ (%) | Nuclear | $W/W_o$ (%) |
|---|---|---|---|---|
| Structure groups | (155,529) | (41.6) | (94,224) | (22.9) |
| Wing | 41,217 | | 48,527 | |
| Tail - Horizontal | 3,738 | | 2,936 | |
| - Vertical | 1,202 | | - | |
| Body | 82,095 | | 15,987 | |
| Alighting gear - Main | 14,700 | | 13,846 | |
| - Auxiliary | | | | |
| Engine section or nacelle group | 11,152 | | 7,160 | |
| Air induction system | - | | 3,533 | |
| Wingtip fins | 965 | | 1,775 | |
| Arresting gear | 460 | | 460 | |
| Propulsion group | (17,525) | (4.7) | (209,400) | (50.9) |
| Engine (as installed) | 10,050 | | 13,541 | |
| Accessory gearboxes & drives | 758 | | 624 | |
| Exhaust system | 862 | | 1,048 | |
| Cooling & drain provisions | 102 | | 83 | |
| Engine controls | 126 | | 104 | |
| Starting system | 205 | | - | |
| Fuel system | 5,422 | | - | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Reactor/shield & installation | | | 194,000 | |
| Equipment groups | (27,994) | (7.5) | (49,975) | (12.1) |
| Flight controls | 2,378 | | 2,216 | |
| Auxiliary powerplant | - | | - | |
| Instruments | 760 | | 760 | |
| Hydraulic & pneumatic | 1,504 | | 1,467 | |

TABLE 26. STRIKE SELECTED VEHICLES WEIGHT SUMMARY (CONCL)

| | Liquid hydrogen | $W/W_o$ (%) | Nuclear | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Electrical | 6,622 | | 6,462 | |
| Avionics | 9,980 | | 9,980 | |
| Armament | 4,090 | | 4,090 | |
| Furnishings and equipment | 1,480 | | 1,480 | |
| Air conditioning | 1,100 | | 1,100 | |
| Anti-icing | | | | |
| Photographic | 80 | | 80 | |
| Load & handling | | | | |
| Crew shield | | | 22,340 | |
| Total weight empty | 201,048 | 53.8 | 353,599 | 85.9 |
| Crew | 1,080 | | 1,080 | |
| Fuel - Unusable | 953 | | - | |
| Fuel - Usable | 113,386 | 30.4 | - | - |
| Oil - Engine | 465 | | 400 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Missiles | 50,000 | 13.4 | 50,000 | 12.1 |
| Flares | 270 | | 270 | |
| Missile launchers | 5,100 | | 5,100 | |
| Equipment | | | | |
| $O_2$ | 100 | | 100 | |
| Chaff | 1,020 | | 1,020 | |
| Total useful load | 172,374 | 46.2 | 57,970 | 14.1 |
| Takeoff gross weight | 373,422 | 100.0 | 411,569 | 100.0 |
| Flight design gross weight | 373,422 | | 411,569 | |

distance can be improved by an improvement in high-lift devices without the reoptimization procedure.

A second selection criteria adopted for this mission was a 0.85 penetration Mach number. Survivability studies conducted on the B-1 low-altitude profile showed this Mach number to be most advantageous; therefore, it has been maintained throughout the study.

## Air Superiority Vehicles

The two vehicles which were configured for the air superiority mission used boron and pentaborane fuels. The estimated input weights for these vehicles were based on the thrust loading (1.19) and wing loading (70.4 psf) selected for the JP-fueled basepoint. As for the strike vehicles, the estimated input weights were used along with the results of the aerodynamic technical evaluation and with a parametric sizing evaluation to select vehicles capable of accomplishing the air superiority mission. Table 27 shows the selected boron air superiority vehicle characteristics, while Table 28 summarizes the pentaborane vehicle. As can be seen, these fighters weigh from 17,000 to 18,000 pounds. A weight breakdown summary for both selected vehicles is included in Table 29.

A requirement for a specific excess power of 1,200 feet/second at sea level, along with a 1,500-foot takeoff distance, previously determined the fighter thrust and wing loadings. As Tables 27 and 28 show, both the boron and pentaborane vehicles either meet or nearly meet the $P_S$ requirement. However, both vehicles require only 1,200 feet to take off. As before, reoptimization can lead to the attainment of the 1,500-foot requirement. However, previous results show that impact of the potential improvements to be minor, and a reoptimization study was not conducted.

## Area Interceptor Vehicles

As in the air superiority fighters, the two vehicles which were configured for this mission used boron and pentaborane fuels. Based on the JP-powered basepoint interceptors, the thrust loading and wing loading were selected as 1.16 and 68.3 psf, respectively. The estimated input weights were used along with aerodynamics to select vehicles capable of accomplishing the area interceptor mission. The selected boron area interceptor vehicle characteristics are presented in Table 30, while Table 31 summarizes the pentaborane vehicle. As can be seen, these interceptors weigh from 21,000 to 22,500 pounds. A weight breakdown summary for both selected vehicles is in Table 32.

TABLE 27. SELECTED BORON AIR SUPERIORITY VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 18,176 lb |
| Wing area | 258 sq ft |
| Wing loading (takeoff) | 70.4 psf |
| Propulsion system - 2 advanced technology F100 engines using boron fuel | |
| Thrust loading (takeoff) | 1.19 |
| Weight fuel | 4,389 lb |
| Weight payload | 800 lb |
| Takeoff distance | 1,219 ft |
| Specific excess power at sea level | 1,215 ft/sec |

TABLE 28. SELECTED PENTABORANE AIR SUPERIORITY VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 17,316 lb |
| Wing area | 246 sq ft |
| Wing loading (takeoff) | 70.4 psf |
| Propulsion system - 2 advanced technology F100 engines using pentaborane fuel | |
| Thrust loading (takeoff) | 1.19 |
| Weight fuel | 3,703 lb |
| Weight payload | 800 lb |
| Takeoff distance | 1,219 ft |
| Specific excess power at sea level | 1,166 ft/sec |

TABLE 29. AIR SUPERIORITY SELECTED VEHICLES WEIGHT SUMMARY

| | Penta-borane | W/W (%)$^{o}$ | Boron | W/W (%)$^{o}$ |
|---|---|---|---|---|
| Structure groups | (4,993) | (28.8) | (4,765) | (26.2) |
| Wing | 1,062 | | 1,104 | |
| Tail - Horizontal | 156 | | 162 | |
| - Vertical | 126 | | 118 | |
| Body | 2,471 | | 2,187 | |
| Alighting gear - Main | 395 | | 421 | |
| - Auxiliary | 100 | | 105 | |
| Engine section or nacelle | 26 | | 28 | |
| Air induction system | 595 | | 578 | |
| Arresting gear | 62 | | 62 | |
| Propulsion group | (2,040) | (11.8) | (2,130) | (11.7) |
| Engine (as installed) | 1,647 | | 1,714 | |
| Accessory gearboxes & drives | | | | |
| Exhaust system | | | | |
| Cooling & drain provisions | | | | |
| Engine controls | 23 | | 24 | |
| Starting system | | | | |
| Fuel system | 370 | | 392 | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Equipment groups | (4,590) | (26.5) | (4,680) | (25.8) |
| Flight controls | 624 | | 685 | |
| Auxiliary powerplant | 257 | | 264 | |
| Instruments | 120 | | 120 | |
| Hydraulic & pneumatic | 270 | | 294 | |
| Electrical | 424 | | 437 | |
| Avionics | 1,450 | | 1,450 | |

TABLE 29. AIR SUPERIORITY SELECTED VEHICLES WEIGHT SUMMARY (CONCLUDED)

| | Penta-borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Armament | 550 | | 550 | |
| Furnishings and equipment | 240 | | 240 | |
| Air conditioning | 655 | | 640 | |
| Anti-icing | | | | |
| Photographic | | | | |
| Load & handling | | | | |
| Total weight empty | 11,623 | 67.1 | 11,575 | 63.7 |
| Crew | 215 | | 215 | |
| Fuel - Unusable | 55 | | 280 | |
| Fuel - Usable | 3,703 | 21.4 | 4,389 | 24.1 |
| Oil - Engine | 65 | | 62 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Gun - 20 MM | 200 | | 200 | |
| Ammo - 940 Rd/Al cases | 375 | | 375 | |
| Missiles - (4) air-to-air | 800 | 4.6 | 800 | 4.4 |
| Missile launchers - Wingtip | 200 | | 200 | |
| Equipment | | | | |
| Chute & survival kit | 60 | | 60 | |
| LOX & converter | 20 | | 20 | |
| Total useful load | 5,693 | 32.9 | 6,601 | 36.3 |
| Takeoff gross weight | 17,316 | 100.0 | 18,176 | 100.0 |
| Flight design gross weight | 17,316 | | 18,176 | |

TABLE 30. SELECTED BORON AREA INTERCEPTOR VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 22,652 lb |
| Wing area | 332 sq ft |
| Wing loading (takeoff) | 68.3 psf |
| Propulsion system - 2 advanced technology F100 engines using boron fuel | |
| Thrust loading (takeoff) | 1.16 |
| Weight fuel | 5,328 lb |
| Weight payload | 2,000 lb |
| Takeoff distance | 1,217 ft |
| Specific excess power at sea level | 1,200 ft/sec |

TABLE 31. SELECTED PENTABORANE AREA INTERCEPTOR VEHICLE CHARACTERISTICS

| | |
|---|---|
| Takeoff gross weight | 21,230 lb |
| Wing area | 311 sq ft |
| Wing loading (takeoff) | 68.3 psf |
| Propulsion system - 2 advanced technology F100 engines using pentaborane fuel | |
| Thrust loading (takeoff) | 1.16 |
| Weight fuel | 4,371 lb |
| Weight payload | 2,000 lb |
| Takeoff distance | 1,218 ft |
| Specific excess power at sea level | 1,155 ft/sec |

TABLE 32. AREA INTERCEPTOR SELECTED VEHICLES WEIGHT SUMMARY

| | Penta-borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Structure groups | (6,594) | (31.1) | (6,600) | (29.1) |
| Wing | 1,324 | | 1,414 | |
| Tail - Horizontal | 211 | | 230 | |
| - Vertical | 192 | | 209 | |
| Body | 1,695 | | 1,608 | |
| Alighting gear - Main | 489 | | 524 | |
| - Auxiliary | 121 | | 130 | |
| Engine section or nacelle | 1,726 | | 1,685 | |
| Air induction system | 768 | | 732 | |
| Arresting gear | 68 | | 68 | |
| Propulsion group | (2,467) | (11.6) | (2,633) | (11.6) |
| Engine (as installed) | 1,990 | | 2,137 | |
| Accessory gearboxes & drives | | | | |
| Exhaust system | | | | |
| Cooling & drain provisions | | | | |
| Engine controls | 25 | | 27 | |
| Starting system | | | | |
| Fuel system | 452 | | 469 | |
| Fan (as installed) | | | | |
| Hot-gas duct system | | | | |
| Equipment groups | (4,778) | (22.5) | (4,813) | (21.2) |
| Flight controls | 640 | | 661 | |
| Auxiliary powerplant | 285 | | 295 | |
| Instruments | 120 | | 120 | |
| Hydraulic & pneumatic | 285 | | 286 | |
| Electrical | 448 | | 466 | |
| Avionics | 1,450 | | 1,450 | |

TABLE 32. AREA INTERCEPTOR SELECTED VEHICLES WEIGHT SUMMARY (CONCLUDED)

| | Penta-borane | $W/W_o$ (%) | Boron | $W/W_o$ (%) |
|---|---|---|---|---|
| Equipment groups (Cont) | | | | |
| Armament | 655 | | 655 | |
| Furnishings and equipment | 240 | | 240 | |
| Air conditioning | 655 | | 640 | |
| Anti-icing | | | | |
| Photographic | | | | |
| Load & handling | | | | |
| Total weight empty | 13,839 | 65.2 | 14,046 | 62.0 |
| Crew | 215 | | 215 | |
| Fuel - Unusable | 62 | | 346 | |
| Fuel - Usable | 4,371 | 20.6 | 5,328 | 23.5 |
| Oil - Engine | 88 | | 62 | |
| Passengers/cargo | | | | |
| Armament | | | | |
| Gun - 20 mm | 200 | | 200 | |
| Ammo - 940 Rd/Al cases | 375 | | 375 | |
| Missiles - (4) air-to-air | 2,000 | 9.4 | 2,000 | 8.8 |
| Equipment | | | | |
| Chute & survival kit | 60 | | 60 | |
| LOX & converter | 20 | | 20 | |
| Total useful load | 7,391 | 34.8 | 8,606 | 38.0 |
| Takeoff gross weight | 21,230 | 100.0 | 22,652 | 100.0 |
| Flight design gross weight | 21,230 | | 22,652 | |

The requirement for a specific excess power of 1,200 feet/second at sea level is either met or is very close to being met. Both vehicles, however, require only 1,200 feet to take off. Reoptimization can lead to the attainment of the 1,500-foot requirement, but potential improvements are predicted to be minor and was not conducted.

The assessment of the impact of these alternate fuels is shown in Section IV.

## Section IV

## IMPACT ACCESSMENT

The assessment of the impact of alternate fuels on aircraft configuration characteristics was conducted in three areas: systems effectiveness and performance; reliability, maintainability, and safety; and system cost. In all cases, the petroleum-fueled baseline vehicle was used as a point of reference from which the other vehicles were evaluated.

### SYSTEMS EFFECTIVENESS AND PERFORMANCE

Because the alternate fuel vehicles were evaluated with thrust loading and wing loading equal to the petroleum-fuel baseline vehicles, most of the mission performance capabilities specified were held constant. Variations in maneuver performance and takeoff distance are results of small differences in estimated aerodynamic characteristics. As previously performed, vehicles for each mission will be discussed separately.

### STRATEGIC STRIKE VEHICLES

The critical design parameters for these vehicles were the penetration Mach number and takeoff distance. Various maneuver points were tracked as were takeoff and landing distances (ground roll and over a 50-foot obstacle). Table 33 compares these values for the three selected vehicles. As can be seen, the takeoff gross weight spread from lightest to heaviest is less than 10 percent of the baseline vehicle, however, the fuels selected result in somewhat different characteristics. The increase in takeoff distance is primarily due to increased ground roll caused by a higher liftoff speed requirement. This, in turn, is caused by a reduction in attainable lift coefficient. It is felt that an improvement in high-lift devices (back to baseline levels) would solve this problem for minor variations in weight. Landing distances, however, are more of a problem. The difference in ground roll between the baseline and alternate fuel vehicles is primarily due to landing wing loading variations. The nuclear-fueled vehicle lands at takeoff gross weight less payload only, while the liquid hydrogen vehicle deducts a low-density, high-energy content fuel plus payload. The net result is that the nuclear vehicle has a landing wing loading more than three times that of the baseline and, therefore, a greatly increased landing distance. The improved takeoff aerodynamics will help in this instance also, but the final results will still be divergent. The same effect is shown on the cruise ceiling results. The heavier nuclear and hydrogen vehicles (at start penetration weight) end at a lower altitude than the conventional baseline. On the

TABLE 33. STRIKE VEHICLE PERFORMANCE COMPARISON

| | Petroleum fuel (JP-4) | Liquid hydrogen fuel | Nuclear fuel |
|---|---|---|---|
| Takeoff gross weight - lb | 404,000 | 373,421 | 411,569 |
| Takeoff distance (total) - ft | 6,987 | 8,808 | 8,595 |
| Ground roll - ft | 5,879 | 7,586 | 7,382 |
| Landing distance (total) - ft | 1,990 | 3,634 | 5,286 |
| Ground roll - ft | 1,267 | 2,583 | 4,029 |
| Landing weight - lb | 116,463 | 211,533 | 361,569 |
| Landing wing loading - psf | 29.1 | 57.2 | 88.7 |
| Penetration Mach at 50 ft | 0.85 | 0.85 | 0.85 |
| Maximum speed (SL) - M | 0.87 | 0.86 | 0.92 |
| Cruise ceiling altitude - ft | 49,000 | 38,000 | 36,000 |

other hand, the lower zero lift drag for the nuclear vehicle (due to reduced skin friction) results in a higher maximum sea-level speed, while the increased hydrogen vehicle zero lift drag decreases the maximum sea-level speed. The effect of these variations on overall system effectiveness is considered negligible.

The general area of stealth must be evaluated as part of the measure of system effectiveness. The area of visual stealth is generally regarded as a function of the projected area of the vehicle, therefore, the change in size can be related to visibility. Radar cross section can be related to the size of the vehicle also, if no effort is made toward reduction with size variation. The infrared signature results primarily from skin friction (at penetration) and the engine exhaust, and size again effects the first of these. Table 34 summarizes the stealth aspects of the strike vehicles.

The increased size of the hydrogen-fuel vehicle is detrimental to all three functions assessed, and no benefit can be attributed to the hydrogen fuel for engine plume IR reduction. The nuclear-vehicle size is slightly less than the baseline which produces a small benefit for optical visibility, but as the radar "visibility" is proportional to the square root of the optical visibility, there is little benefit in that area. As before, the size reduction also helps the IR cross section, but a much larger influence

comes from lack of a hot gas effluent due to the closed cycle selected for the nuclear engine. The overall IR cross section would therefore be much reduced. A radiation cross section from the reactor has not been estimated, but its effect will have to be determined for a complete stealth analysis.

Overall systems effectiveness evaluation would show the nuclear vehicle as the most effective of the strike versions, with the hydrogen vehicle less effective than either nuclear or JP-fueled versions. The nuclear vehicle has an added effectiveness parameter in that its entire radius can be flown at low altitude should en route sanctuary be lost with no increase in vehicle size.

TABLE 34. STRATEGIC STRIKE STEALTH ASSESSMENT

| | Hydrogen fuel | Nuclear fuel |
|---|---|---|
| Visibility | < Baseline | > Baseline |
| Radar cross section | < Baseline | = Baseline |
| IR cross section | < Baseline | >> Baseline |

AIR SUPERIORITY VEHICLES

The critical design parameters for these vehicles were maximum sea-level maneuverability and takeoff distance. Again, various maneuver points and takeoff and landing distances were tracked. Table 35 compares the results for the selected vehicles for this mission. The takeoff gross weights of the alternate fuel vehicles are between 40 and 45 percent less than that of the conventional fuel version. The takeoff distance shows less than the required value due to a lower drag than expected and, hence, an improved thrust/drag ratio, as well as improved lift characteristics from the baseline vehicles. The landing distances are degraded due to higher landing wing loadings, as in the strike mission, but the aerodynamics improvement is sufficient to result in an overall reduction in distance. Drag due to lift, both subsonic and supersonic, is not as good as expected from the parameteric variation, however, wave drag analysis showed better results such that the supersonic 1-g normal load factor values are improved but the sustained load factors available are slightly degraded. Subsonic maneuverability shows slightly reduced 1-g levels and corresponding reductions in sustained load factors. Transonic maneuver shows the improved wave drag to a lesser degree at 1 g

TABLE 35. AIR SUPERIORITY PERFORMANCE COMPARISON

| | Petroleum fuel (JP-4) | Boron fuel | Pentaborane fuel |
|---|---|---|---|
| Takeoff gross weight - lb | 30,700 | 18,176 | 17,316 |
| Takeoff distance (total) - ft | 1,499 | 1,219 | 1,219 |
| Ground roll - ft | 647 | 495 | 495 |
| Landing distance (total - ft | 3,217 | 2,912 | 2,982 |
| Ground roll - ft | 2,257 | 2,093 | 2,158 |
| Specific excess power - fps | | | |
| 0.9 M/30,000 ft/1 g | 530 | 506 | 490 |
| 1.2 M/30,000 ft/1 g | 417 | 407 | 466 |
| 1.8 M/45,000 ft/1 g | 407 | 467 | 505 |
| Sustained load factor - g | | | |
| 0.9 M/30,000 ft | 5.15 | 4.21 | 4.12 |
| 1.2 M/30,000 ft | 4.14 | 3.80 | 4.01 |
| 1.8 M/45,000 ft | 3.17 | 2.81 | 2.89 |
| Combat ceiling - ft | <60,000 | <60,000 | <60,000 |

but still reflects the reduced levels at sustained load factors. Again, because the vehicles were designed for approximately constant performance, it is considered to result in a negligible effect on system effectiveness due to these changes.

The vehicle size reduction contributes to stealth aspects in the same manner as previously described, i.e., less IR signature due to less skin friction area, and less optical visibility and RCS due to the smaller size. Although the same engine cycle is used, the smaller size engines (over 40 percent less airflow and thrust) should reduce the IR signature in this area also. The two alternate fuel vehicles are considered equal due to the closeness in size, and both are improved in comparison to the JP-fuel baseline vehicle.

AREA INTERCEPTOR VEHICLES

Takeoff distance and maximum sea-level maneuverability were the critical design parameters for the area-interceptor vehicles also. Table 36 compares these variables and others tracked for this mission. The overall results are nearly the same as for the air-superiority vehicles, that is, a gross weight

TABLE 36. AREA INTERCEPTOR PERFORMANCE COMPARISON

| | Petroleum fuel (JP-4) | Boron fuel | Pentaborane fuel |
|---|---|---|---|
| Takeoff gross weight - lb | 34,250 | 22,652 | 21,230 |
| Takeoff distance (total) - ft | 1,497 | 1,217 | 1,218 |
| Ground roll - ft | 652 | 495 | 496 |
| Landing distance (total) - ft | 3,038 | 2,673 | 2,736 |
| Ground roll - ft | 2,118 | 1,914 | 1,964 |
| Specific excess power - fps | | | |
| 0.9 M/30,000 ft/1 g | 541 | 512 | 496 |
| 1.2 M/30,000 ft/1 g | 406 | 362 | 356 |
| 2.0 M/60,000 ft/1 g | 62 | 95 | 119 |
| Sustained load factoring | | | |
| 0.9 M/30,000 ft | 5.46 | 4.35 | 4.25 |
| 1.2 M/30,000 ft | 4.23 | 4.03 | 3.97 |
| 2.0 M/60,000 ft | 1.31 | 1.38 | 1.46 |
| Combat ceiling - ft | <60,000 | <60,000 | <60,000 |

of 35 to 40 percent less than the baseline and performance comparable. The takeoff and landing distances are better for the same reasons, but the transonic aerodynamics (particularly wavedrag) are not as good, causing a small loss in Mach 1.2 maneuverability. Wave drag optimization at Mach 2.0 improves the performance at higher speeds at some cost in transonic characteristics, and these characteristics are exhibited here as shown by the improved Mach 2.0 maneuverability. The overall impact will again be a negligible variation in systems effectiveness due to performance variation.

The stealth aspects of these vehicles will again be the same as those for the air-superiority vehicles with both of the alternate fuel vehicles being better than the JP-fueled vehicle.

Survivability/vulnerability studies were not conducted, but may be generally addressed. Previous studies at Rockwell have shown that a decrease in "vulnerable-area" results in a decreased vulnerability. The vulnerable area of all the alternate-fuel vehicles, except liquid hydrogen, is less than the corresponding JP-fuel vehicles. The powdered boron-fuel versions are the least vulnerable due to the lack of fuel in the wing as well as the smaller physical size, and the nuclear vehicle, in spite of its larger physical size, has few vulnerable areas due to the design of its propulsion system. The flammability of the alternate fuels favors the boron and nuclear fuels, while the pentaborane results in an increase. Survivability is related to the stealth aspects already considered and the vulnerability; therefore, all the alternate-fuel vehicles (except liquid hydrogen) should be rated as more survivable with the boron-fueled versions rating the highest.

## RELIABILITY, MAINTAINABILITY, AND SAFETY

The reliability, maintainability, and safety aspects of alternate-fuels impact assessment have been qualitatively made and are presented here. Maintainability and reliability were considered to be primarily affected by the development stage of the system, the properties of the fuels, and the system complexity. The development stage of a system affects the reliability in that a longer development time (a more "mature" system) usually shows more reliability due to reduction of early design problems and unexpected trouble areas. Maintainability is similarly improved with development time as problem areas which cannot be eliminated can at least be designed for easier maintenance. Fuel properties impact the reliability of a system due to the wear, erosion, and chemical interactions of the fuels with other systems elements. Maintenance requirements and the ability to perform those requirements are similarly affected. Increasing system complexity also has a generally detrimental effect on both reliability and maintainability.

The safety evaluation of the alternate fuels concentrated on the properties of the fuels and their handling requirements. The more stringent requirements for safety and handling are the result of potentially more dangerous fuels. Each of the fuels selected will be addressed independently rather than discussing each vehicle class.

### NUCLEAR FUEL

There is almost no single subject that has created more long-term heated discussion than the nuclear power generating station with attendant reliability and safety considerations. These discussions would seem insignificant in comparison to those raised over a nuclear aircraft with possibilities of an inflight failure leading to a crash. These discussions notwithstanding,

the reliability of nuclear powerplants have shown the feasibility of use in an air vehicle through years of use in stationary and mobile (satellites and naval vessels) applications. Therefore, the reactor development stage can be considered more advanced than a new developmental system, and the system reliability and maintainability will be higher. The reactor comprises only a small part of the total system, however, and it is expected that the total system reliability will be reduced due to developments required for the high-temperature helium ducting and the closed cycle turbine drive for the engines as well as heat exchangers and other heretofore nonaircraft systems. Maintenance requirements for the reactor are infrequent so that, while complex, basic maintainability is better than the JP-fuel counterpart. The remainder of the propulsion system is, again, largely unknown and, therefore, will rate lower than the comparison vehicle. The net result for both reliability and maintainability is estimated to be near break-even. Safety aspects of nuclear fuel are rated below those of more conventional fuel due primarily to the requirements of the flight weight design reactor shield. The shield provides a two-stage protection for the ground crew for servicing the vehicle by virtue of its filled/hollow shell design. This element causes some increase in safety risk to ground personnel before the filled shield is implemented, particularly those whose task it would be to load and unload the shield. This risk would be minimized by design of the specialized ground equipment necessary to complete the function. Safety risk due to impact during an accident has already been discussed, but a detail design would be necessary to determine if the referenced report parameters could be met for a flight weight design. The overall assessment of use of nuclear power as an alternate fuel shows a break-even to small loss for reliability, maintainability, and safety.

## LIQUID HYDROGEN

Liquid hydrogen, as an alternate fuel, presents a set of problems totally unlike those of nuclear power. Reliability records of cryogenic machinery primarily limited to rocket-powered systems are useful, but not totally accurate as the propulsion units are essentially constant fuel flow versus the highly variable requirements of the strike mission. The added systems complexity due to throttling will reduce the reliability levels from those of the rocket systems, but the results should not be significantly different from the conventional fuels. Maintainability should similarly be approximately that of the conventional fuel vehicle and, due to the engine cycle similarity the engine, as well as its subsystems, should produce similar levels. Because the hydrogen fuel usually requires preheating before combustion, the more severe effects of cryogenic fuel handling are degraded, but the preheater does add an area for problems which yields a complete evaluation of reliability and maintainability of slightly lower than conventional vehicles.

Safety standards for handling cryogenic liquids are much more severe than conventional fuel liquids, and liquid hydrogen, in particular, requires extra precautions due to its volatile nature. The explosion danger of gaseous hydrogen is somewhat compensated for by the weight of the gas being small and, therefore, rising rather than collecting, but the extreme range of flammability in air (from 4 to 74 percent in contrast to JP-4 from about 1 to 6 percent) adds to the magnitude of the problem. The overall safety rating for liquid hydrogen is therefore, significantly lower than conventional fuel.

POWDERED BORON

Powdered boron fuel affects the system reliability through the short development cycle possible for fuel containment, feed, and metering systems. Allowable moisture content limits put constraints on containment, and fuel feed and metering systems are essentially handling a grade of abrasive. Powdered fuel studies using coal dust have shown extreme turbine abrasion due to unburnt particles as impingement, and, in fact, larger particles were responsible for breaking large pieces from the turbine blades. A solid-particle trap (such as used on the inlet air to the Army turbine-engined tank propulsion system) might be developed for the hot section, but this would be a new source for reliability and/or maintenance problems, and the reverse flow design could impact engine efficiencies. Another potential problem for reliability is created by the chemical composition of the exhaust. Combustion products of boron will include boric acid to some degree, and the concentration would determine the extent to which reliability would be affected. The overall evaluation of powdered boron would therefore indicate that reliability and maintainability would be lower than for a conventional hydrocarbon fuel.

The powdered boron fuel effects on system safety are largely positive due to the low flammability of the fuel, however, the previously mentioned exhaust composition could create safety problems again dependent on the concentration of the boric acid present.

PENTABORANE

The evaluation of pentaborane as an alternate fuel resulted in a reliability and maintainability assessment of lower values than the present hydrocarbon fuels. As for the boron fuel, this is partially a result of boric acid in the exhaust gas, however, another unusual problem occurs with this fuel. When atomized, such as by the fuel injectors, the fuel forms a solid which gains size until it breaks loose and cascades through the hot section of the engine as a solid. Minimization of this phenomenon can be accomplished by

injecting a blast of water at intervals as the solid is water-soluble, but the complexity added is a new source of additional reliability and maintainability problems. Another potential solution might be a fuel additive which reduces or eliminates the solid formation. Additional research into the problem is required in this area before the magnitude may be quantified. A third reliability and maintainability decrement must be applied due to the spontaneous ignition property of the fuel when exposed to air. This property also causes a decrease in safety assessment as well. The boric acid in the exhaust further reduces the safety level, but, as on the boron fuel, the magnitude of the reduction is unknown without further study.

## LIFE-CYCLE COST ANALYSIS

A preliminary life-cycle cost (LCC) analysis was performed on the candidate weapon system designs to determine if a potential cost advantage could be associated with the alternate fuels configurations. Included in these cost assessments were the research, development, test and evaluation (RDT&E), force acquisition, and peacetime operations and support (O&S) costs. Special emphasis was placed on the LCC sensitivity to the fuel prices assumed for the various alternate fuels.

The cost evaluations were made using the following three in-house parameter cost estimating models:

1. RDT&E model

2. Production cost model (PCM)

3. Fleet cost model (FCOST)

These computer programs were exercised in conjunction with the VSPEP model to calculate the LCC of each configuration as sized to meet the mission requirements. Complexity factors were then applied to the cost model results to account for additional design/development, manufacturing, and peacetime logistics support costs which might be anticipated for the exotic fuels configurations. In the case of the nuclear bomber, discrete cost increments were developed based on the RAND results documented in reference 1. The set of adjustment factors assigned to the various alternate fuel configurations is presented in Table 37. All cost calculations were made in constant FY 1977 dollars.

A summary of the final LCC data (excluding peacetime fuel costs) for the JP-4 configurations (Tables 13 through 15) and alternate fuels configurations is presented in Table 38. The results show that the pentaborane and boron fighter and interceptor designs offer potential LCC savings over their JP-4 counterparts, primarily due to reductions in structural weight and thrust level at constant mission performance. The $LH_2$ bomber appears to be of about equal LCC to the advanced conventional bomber, but the major size penalty and reactor costs associated with the nuclear bomber makes its total cost prohibitive.

Due to the uncertainty in projected costs of the alternate fuel, the addition of peacetime fuel costs to the LCC of the various aircraft systems was done as a function of alternate fuel prices. Figure 31 illustrates the total cost sensitivity of the pentaborane fighter and interceptor for varying pentaborane prices. Break-even points with the JP-4 fighter and interceptor LCC are also shown for the values of JP-4 fuel. The graph indicates that under current JP-4 prices ($0.44 per gallon), the alternate fuel systems are cost effective for pentaborane prices less than $1.00 per pound (FY 1977 basis).

TABLE 37. COST ADJUSTMENT FACTORS FOR ALTERNATE FUEL CONFIGURATIONS

| Aircraft system | Assigned cost factor* | | |
|---|---|---|---|
| | RDT&E | Acquisition (500 aircraft) | Peacetime operations and support (10 years; less fuel) |
| Boron fighter and interceptor | 1.3 | 1.2 | 1.1 |
| Pentaborane fighter and interceptor | 1.3 | 1.2 | 1.1 |
| $LH_2$ bomber | 1.2 | 1.1 | 1.1 |
| Nuclear bomber | + $1.5 billion | + $6.6 billion | + $4.8 billion |

*Factor applied to appropriate parametric cost model estimates to account for complexity/peculiarity of new systems.

TABLE 38. ALTERNATE FUELS COST STATUS
($ FY 1977 M)

| Aircraft | Empty weight (lb) | RDT&E | Acquisition (500 A/C) | Operation and support less fuel (10 yr peacetime) |
|---|---|---|---|---|
| Strategic strike | | (4 prototypes) | | |
| JP-4 fuel | 109,958 | 2,128 | 15,251 | 16,620 |
| Nuclear fuel | 353,599 | 8,907 | 37,325 | 22,067 |
| $LH_2$ fuel | 201,048 | 5,668 | 23,795 | 16,746 |
| Air superiority fighter | | (12 prototypes) | | |
| JP-4 fuel | 18,420 | 1,300 | 4,507 | 3,089 |
| Pentaborane fuel | 11,623 | 1,205 | 3,906 | 2,838 |
| Boron fuel | 11,575 | 1,212 | 3,942 | 2,880 |
| Area interceptor | | (12 prototypes) | | |
| JP-4 fuel | 19,600 | 1,359 | 4,728 | 3,208 |
| Pentaborane fuel | 13,839 | 1,324 | 4,059 | 2,938 |
| Boron fuel | 14,046 | 1,341 | 4,116 | 3,000 |

Figure 32 provides a further breakdown of the LCC sensitivity to fuel price for the boron fighter. Note that as fuel prices rise, the percent of system LCC associated with peacetime fuel consumption becomes very significant. For example fuel costs increase from about 14 to 33 percent of aircraft LCC as boron prices rise from $1.00 to 3.00 per pound. Similar trend data exists for the pentaborane configurations.

These results indicate the importance of the relative price of alternate fuels to JP-4 when comparing the total estimated costs of the various design concepts. Figure 33 quantifies this relationship by showing the LCC savings/increase of the pentaborane fighter to the JP-4 fighter as a function of their relative fuel prices. The graph implies that, under current JP-4 prices, there is an LCC payoff from the pentaborane fighter for up to a 15:1 fuel price ratio to JP-4.

This preliminary cost comparison has shown that there is a potential cost advantage for weapon systems designed to operate on alternate fuels. It should be recognized, however, that the peculiar costs which may be experienced in the design production, and fleet deployment (including

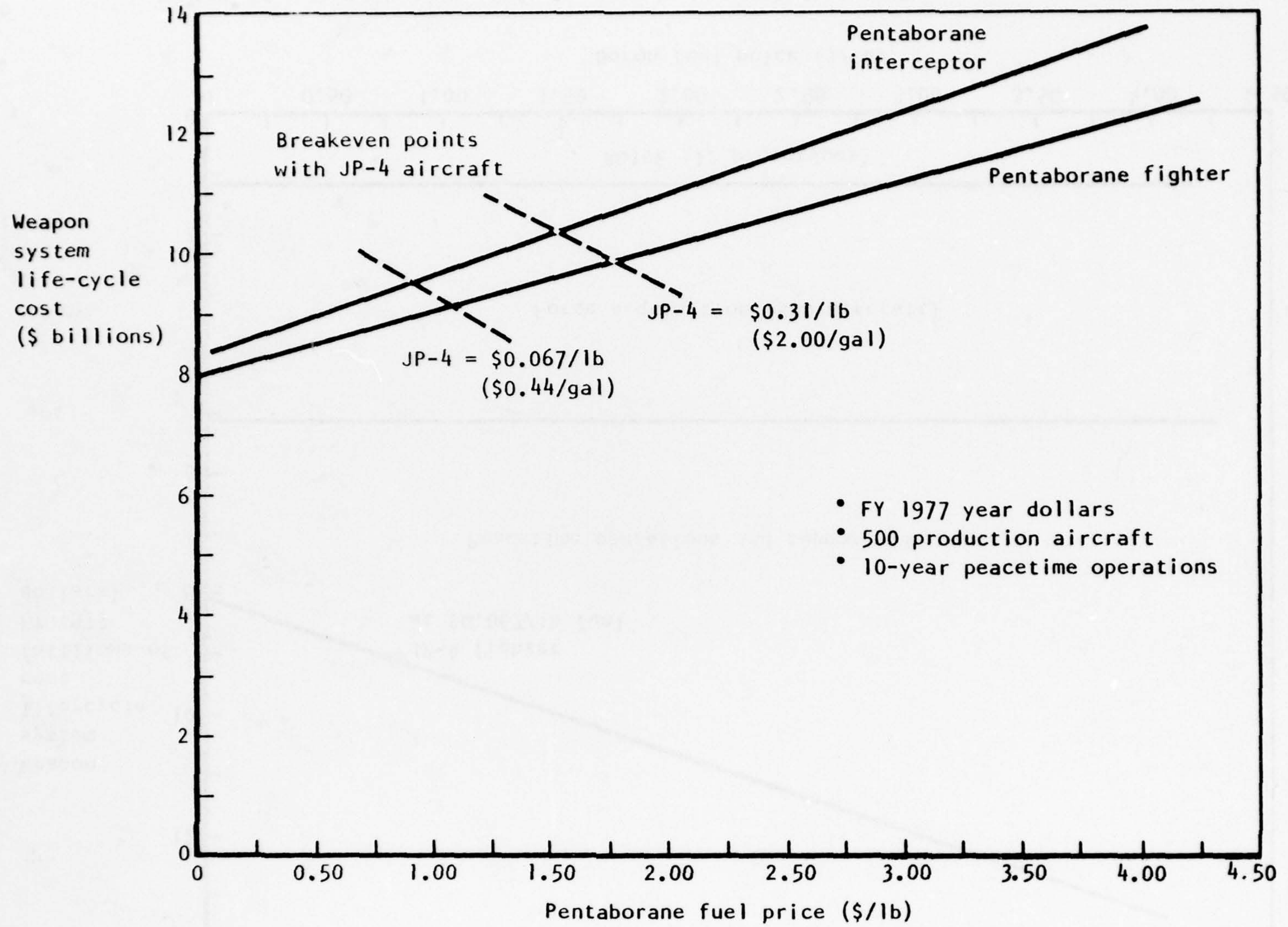


Figure 31. Cost sensitivity to pentaborane fuel price.

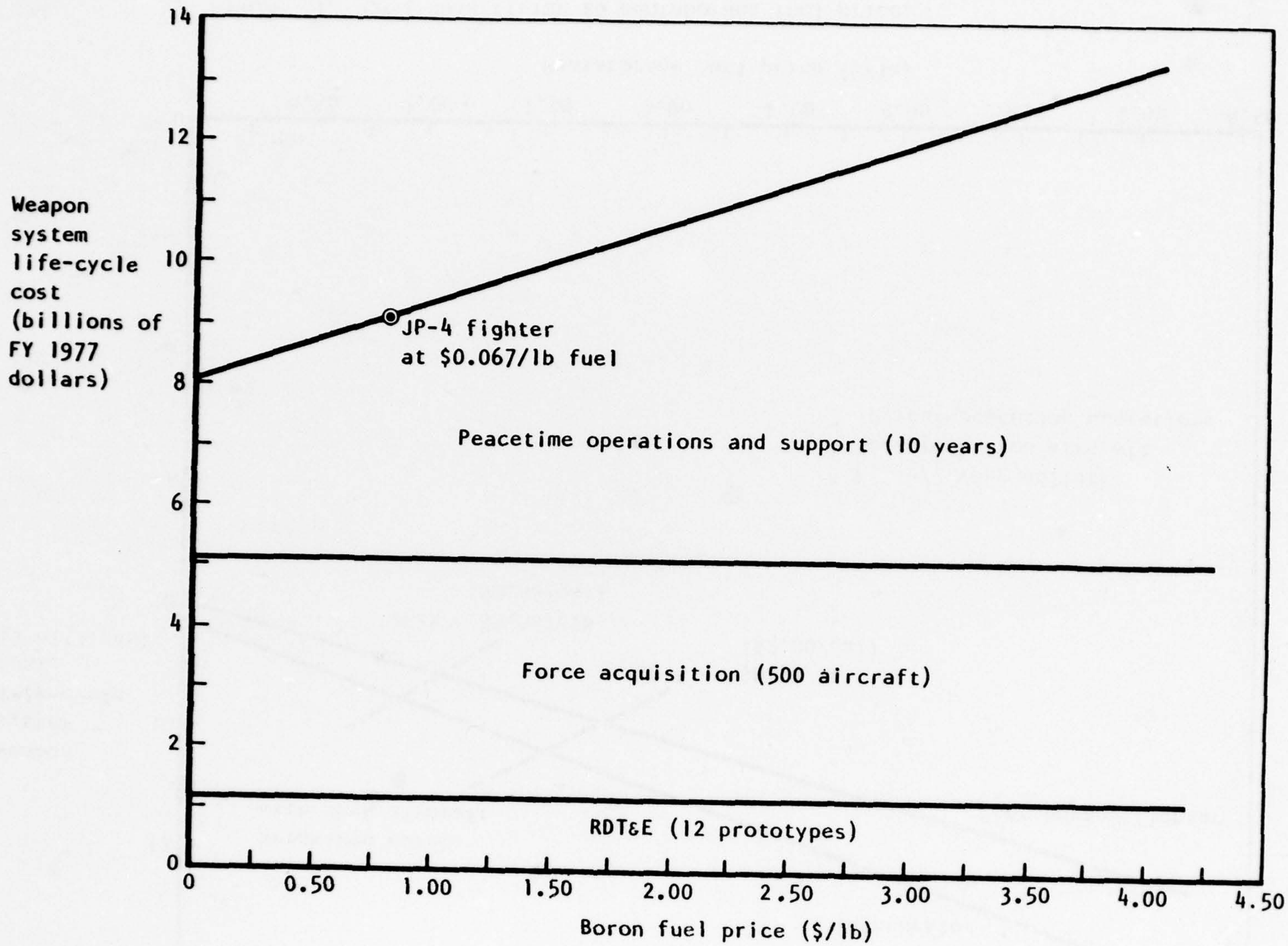


Figure 32. Contribution of fuel costs to boron fighter life-cycle cost.

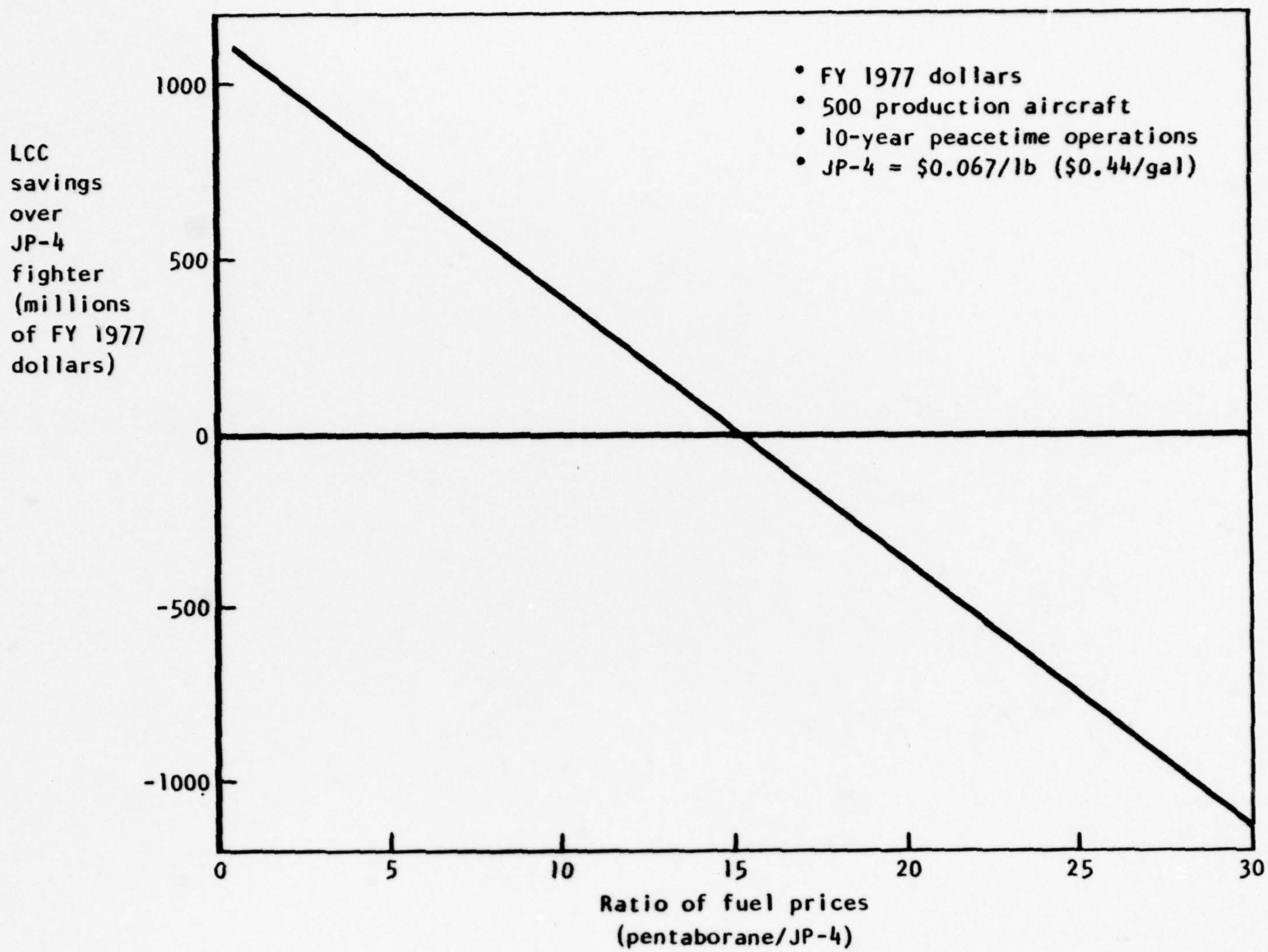


Figure 33. Impact of relative fuel price on LCC savings - pentaborane fighter.

wartime readiness) of these new aircraft systems require more detailed evaluation before it can be concluded that they will reduce future system costs.

## Section V

## CONCLUSIONS

The objective of the study was to determine the impact of alternate fuels on vehicle performance, size, cost, and related characteristics. The study included projections of technology improvements to the year 2000 in the areas of aerodynamics, mass properties, and propulsion. These projections were incorporated into the baseline vehicles for each of the three mission variations (strategic strike, air superiority fighter, and area interceptor) and optimization was conducted parametrically for petroleum fuel basepoint vehicle. Geometry, performance, and cost data were generated for these vehicles.

### ADVANCED TECHNOLOGIES

Technologies which will be available for inclusion in manned aircraft in the year 2000 time period result in significant performance increases. As a result, conventional vehicles of that time will be able to complete the modified mission profiles which current technology vehicles cannot complete (or only at large gross weights). Primary contributors to this improvement are structural weight reductions due to the use of composite primary structure in the lifting surfaces and superplastic-formed/diffusion-bonded (SPF/DB) titanium in the fuselage. Large one-piece components resulting from use of both of these materials will reduce fasteners and joint structure, resulting in cost as well as weight savings. More exotic concepts, such as metal matrix composites and SPF/DB aluminum, could be sufficiently developed to result in further savings.

Propulsion-related items which contributed to the performance increases are primarily engine weight and fuel consumption improvements. Improved component technology will allow higher bypass engines of the future to demonstrate performance characteristics similar to those of low bypass engines of today, resulting in improved specific fuel consumption during part power operations. Further improvements may result from variable-cycle engines, and 2-D nozzles should improve the airframe/propulsion interface, but these were not considered for this study.

Aerodynamic improvements are expected in drag-due-to-lift through winglet designs, variable camber wings (combined mechanical and through the use of aeroelastic tailoring), and the incorporation of relaxed static stability (RSS) for reduced trim drag. Zero lift drag is reduced supersonically by adoption of the high-acceleration cockpit for wave-drag reduction.

## FUELS SCREENING

Alternate fuels were screened to determine those which could produce the most benefit for aircraft systems. The screening was conducted for current inventory vehicles as well as conceptual vehicles of advanced technology, and produced highly divergent results. Current inventory vehicles, because of the costs of retrofit and modifications are generally not suitable for alternate fuels except those which are derived from synthetic crude oil (syncrudes) and whose properties are essentially those of JP-4. Conceptual vehicles, on the other hand, show potentially large benefits from fuels with high-energy content per unit weight and per unit volume, particularly where a supersonic performance requirement exists.

The fuels selected for each conceptual vehicle are the top four ranking fuels (or "families") in terms of heating value in BTU per pound of fuel; i.e., hydrogen (in any form), diborane/pentaborane, beryllium, and boron. In terms of energy density, three of the seven fuels rank in the top four, but two others rank at the bottom of the list. This combination would indicate that the missions are weight sensitive more than drag sensitive and, indeed, the interceptor mission, which appears to be drag sensitive, eliminates the two low-energy density fuels. Further research should therefore be concentrated on higher heating value fuels for smaller vehicles.

## CONFIGURATION DEVELOPMENT

Configuration development for different missions provided results which varied significantly in relation to the level of benefit provided. Current inventory aircraft are generally not suitable for conversion to alternate fuels unless those fuels possess characteristics much like those of JP (i.e., syncrude derived fuels), or unless degradation of the design mission performance is accepted. However, those alternate fuels selected show substantial benefit in takeoff gross weight reduction for fighter and interceptor aircraft while maintaining performance levels, but the fuels selected for the strategic strike vehicles provided less benefit than those for the smaller vehicles. Although the nuclear fueled vehicle is heavier than the basepoint, it should be remembered that the range is essentially infinite.

The results of the conventional (JP) fuel sizing are shown in Table 39. These vehicles were used for comparison purposes to assess the alternate fuel conceptual vehicles.

Tables 40 and 41 summarize the results of the adaptation of the selected alternate fuels to the fighter missions (air superiority and interceptor) and strategic strike, respectively.

TABLE 39. PARAMETRIC SIZING RESULTS

| | Strategic strike vehicle | Air superiority fighter | Area interceptor |
|---|---|---|---|
| Takeoff gross weight - lb | 404,000 | 30,700 | 34,250 |
| Fuel weight - lb | 239,133 | 10,043 | 11,185 |
| Wing loading - psf | 101.0 | 70.4 | 68.3 |
| Thrust loading | 0.26 | 1.19 | 1.16 |
| Takeoff distance - ft | 7,000 | 1,500 | 1,500 |
| Specific excess power ($P_s$) optimum Mach at SL - fps | - | 1,200 | 1,200 |

TABLE 40. PERFORMANCE COMPARISON, AIR SUPERIORITY FIGHTER AND AREA INTERCEPTOR VEHICLES

| | Air superiority fighter | | | Area interceptor | | |
|---|---|---|---|---|---|---|
| | JP fuel | Pentaborane | Boron | JP fuel | Pentaborane | Boron |
| TOGW | 30,700 lb | 17,316 lb | 18,176 lb | 34,250 lb | 21,230 lb | 22,652 lb |
| Fuel weight | 10,043 lb | 3,703 lb | 4,389 lb | 11,185 lb | 4,371 lb | 5,328 lb |
| Takeoff dist | 1,500 ft | 1,219 ft | 1,219 ft | 1,500 ft | 1,218 ft | 1,217 ft |
| Ps at SL | 1,200 fps | 1,150 fps | 1,200 fps | 1,200 fps | 1,155 fps | 1,200 fps |
| Radius | 500 n mi | 500 n mi | 500 n mi | 500 n mi | 500 n mi | 500 n mi |

TABLE 41. PERFORMANCE COMPARISON - STRATEGIC STRIKE VEHICLES

| | JP fuel | Liquid hydrogen | Nuclear |
|---|---|---|---|
| TOGW - lb | 404,000 | 373,421 | 411,569 |
| Fuel weight - lb | 239,133 | 113,386 | - |
| Takeoff dist - ft | 7,000 | 8,808 | 8,595 |
| Pen. Mach | 0.85 | 0.85 | 0.85 |
| Radius - n mi | 3,000 | 3,000 | Unlimited |

IMPACT ASSESSMENT

The qualitative assessment of systems effectiveness shows a benefit for all vehicles except the liquid hydrogen version of the strategic strike vehicle. All the other vehicles show benefits in the areas of stealth and vulnerability which result in increased survivability; however, reduced reliability may be expected for all vehicles using any of the selected alternate fuels.

Life-cycle costs analysis shows that there may be a benefit for the alternate fuels for a life cycle based on a 10-year peacetime usage (calculated in constant FY 1977 dollars). A break-even value for fuel costs occurs at 10 to 15 times the current JP cost of $0.44 per gallon.

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# APPENDIX A

## NUCLEAR PROPULSION SIZING PROCEDURE

ENCLOSURE 1

## Basepoint Reactor Definition

| | |
|---|---|
| Core length | 36 in. |
| Core diameter | 24 in. |
| Reactor volume | 16,286 cu in. |
| Shield length | 130 in. |
| Shield diameter | 104 in. |
| Shield thickness[1] | |
| Side | 40 in. |
| End | 47 in. |
| Shield volume[2] | 1,088,046 cu in. |
| Weight ~ shield[3] | 47,302 lb |
| Weight ~ fixed items (control, etc)[3] | 31,293 lb |
| Weight ~ crew shield (fixed)[3] | 22,335 lb |

NOTES:

1. Shield thickness is defined as shield length (or diameter) minus core length (or diameter) divided by 2.

2. Shield volume is volume of shield cylinder less volume of the core cylinder.

3. Reference ISADS report NA-78-227, Appendix E.

ENCLOSURE 2

## Sizing Ground Rules

I. Reactor/shield

A. Reactor power is proportional to volume.

B. "Compact" reactor has a constant length to diameter ratio equal to 1.25. Basepoint reactor is 36 inches long with a 24 inch core diameter. Power is equal to 0.833 of output for ISADS basepoint.

C. For power output of one-half of basepoint, shield length and diameter may be decreased by 1 foot each. Basepoint is assumed 130 inches long by 104 inches in diameter. Variation for other power ratios are linear between basepoint and 0.5 factor output.

D. Weight is proportional to shield volume. ISADS weight is 47,302 pounds for 1,088,046 cubic inches, plus 31,293 pounds for controls and fixed weight items.

II. Engine

A. Core airflow is proportional to reactor power output. ISADS basepoint is 295.6 pounds per minute.

B. Equivalent airflow for core determines other engine BPR sizing characteristics.

III. Miscellaneous

A. Crew shield is fixed at 22,335 pounds.

B. Installation weight of reactors, ducts, etc is 25 percent of reactor/shield weight.

## ENCLOSURE 3

### Example Problem

Requirements:

1. Thrust - 40,000 pounds SLS uninstalled/reactor.

2. Engine = BPR 2.8, year 2000 IOC, advanced technology based on MF78-03/ advanced technology F101. Engine T/W = 8.0.

3. Reactor L/D = 1.25.

Method:

1. Beginning at 40K thrust and reading up/across,
   Weight of reactor/shield - 72,000 pounds.

2. Resultant reactor diameter approximately 22.65 inches.
   (L = 1.25*D = 28.31 inches)

3. Reactor volume relative to basepoint is 0.84.
   (total volume - 0.84*13,572 = 11,400 cu in.).

4. Shield length is 120 inches, shield diameter is 100 inches.

5. Total system weight (two reactors) is sum of engines, reactor/shield, installation allowance, and crew shield:
   2[40,000/8.0 + 72,000 + 72,000/4] + 22,335 = 212,335 pounds.

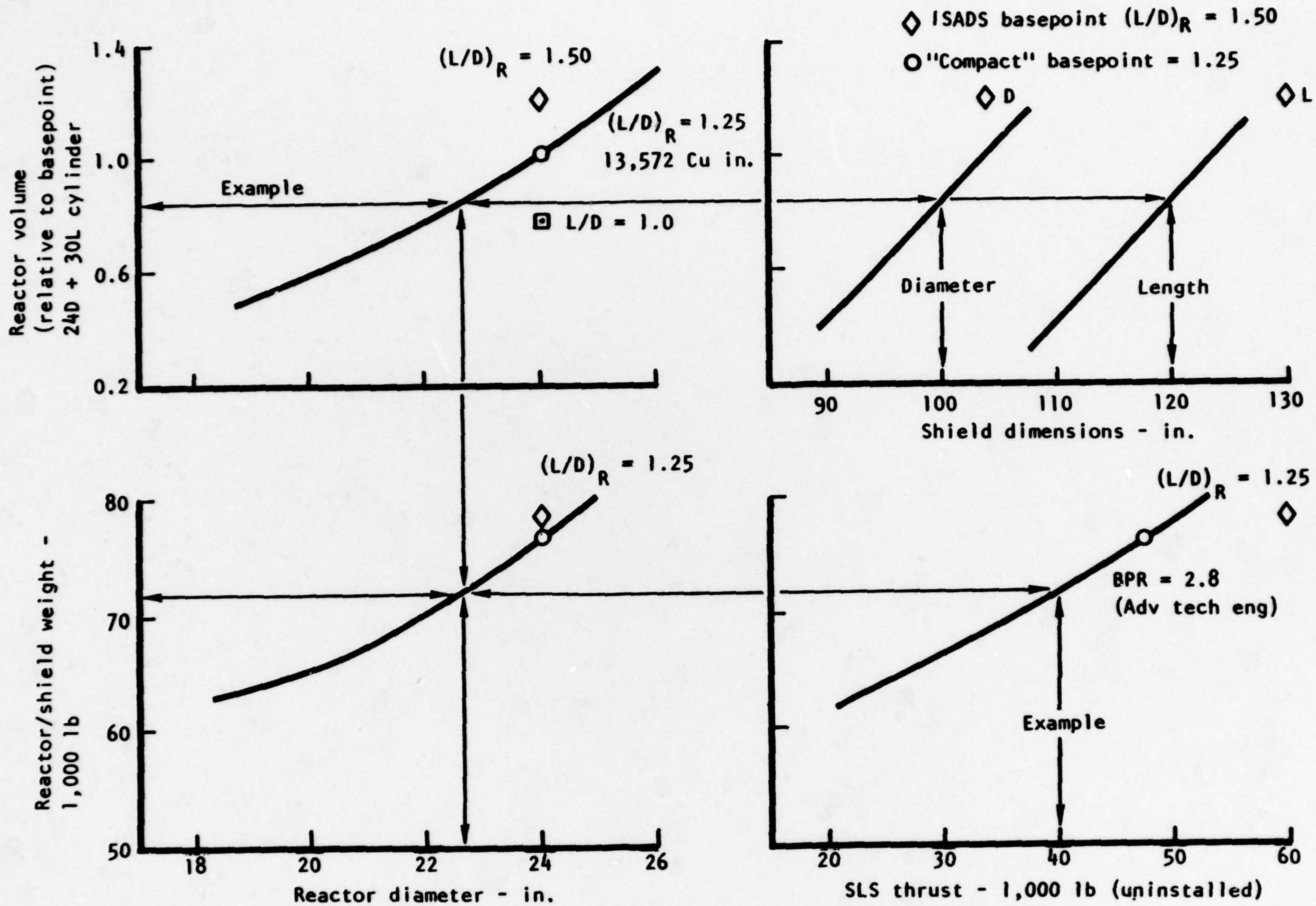


Figure A-1. Nuclear reactor sizing nomogram.



☆U.S.Government Printing Office: 1979 — 657-002/437